Creation of an Ethernet/IP Backbone System for Wyoming's Department of Transportation

Paul J. Andersen
Project Development, Telecommunications
Wyoming Department of Transportation
307-777-4440

Background

- Personal
- Organizational
- Project

Recognition of Need

- Large District 1 ITS Project under construction
  - Construction started Spring 2008 spreading across 225 road miles
  - Devices: 5 DMS, 7 RWIS/Webcams, 13 Flashing Beacons, 8 Road Closure Gates and 7 speed sensors across 15 locations
  - Various communications methods being implemented
- ITS Variable Speed Limit Project (VSL)
  - Fast tracked to be operational for 2008/2009 Winter season
  - Targeting one of the most treacherous travel sections of I-80
  - Devices: 10 VSL Signs, 5 Portable DMS, 10 VSL Speed Sensors
  - Communications in question; one of the most problematic sections of I-80 for comms
- ITS I-80 RWIS/Webcam and DMS Project in Design
  - 2009 Spring construction across estimated 265 miles of I-80 & 60 miles of I-25
  - Devices: 6 DMS, 20 RWIS/Webcams
  - Communications method in question

Need Recognition
(continued)

- Remote Maintenance Shops
  - Existing communications growing outdated and inadequate
  - Various applications/processes require increased comms capacity
  - Productivity diversion from primary duties to administrative duties
- Consideration for other mission systems outside of ITS
  - One of our purposes: provide shared infrastructure
  - Traffic Program
  - Counter Shop
  - Highway Patrol
  - Maintenance Program
- Desire for “routable network” versus circuit based systems

Existing Options

- Commercial Services
  - Cellular
  - Broadband Wireless
  - Traditional (POTS, Copper Circuits)
  - Unavailable, Unreliable, Costly, Standardization, Network Configuration/Security?
- Microwave
  - Commitments to other uses/users
  - Capacity limitations
  - Costly to create “shared” capacity within available resources
  - Existing Frame Relay option limited

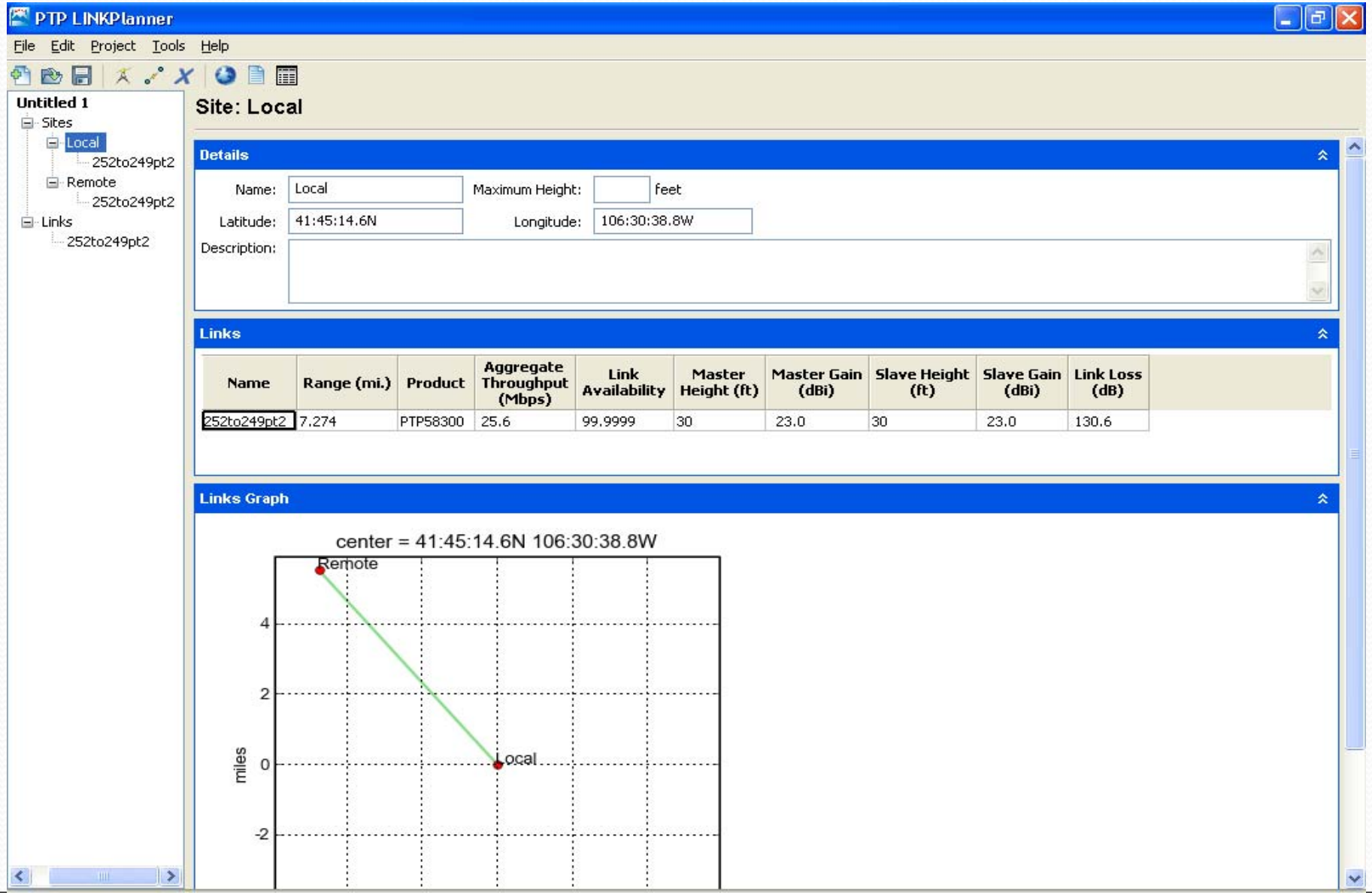
Existing Options
(continued)

- Expand unlicensed spectrum Point-to-Point radio use from roadside comms role to backhaul role
  - Proven use and performance with three existing links
  - Numerous vendors/products available
  - Newer Spectrum Technologies (Dynamic Frequency Selection and Adaptive Modulation)
  - Other considerations (antenna variation, capacity sizing, remote management and monitoring, ethernet/IP)
  - Deployment costs more in line with funds available versus cost of deploying licensed radio systems with similar performance
- Expanding role of unlicensed Point-to-Point radios was option selected

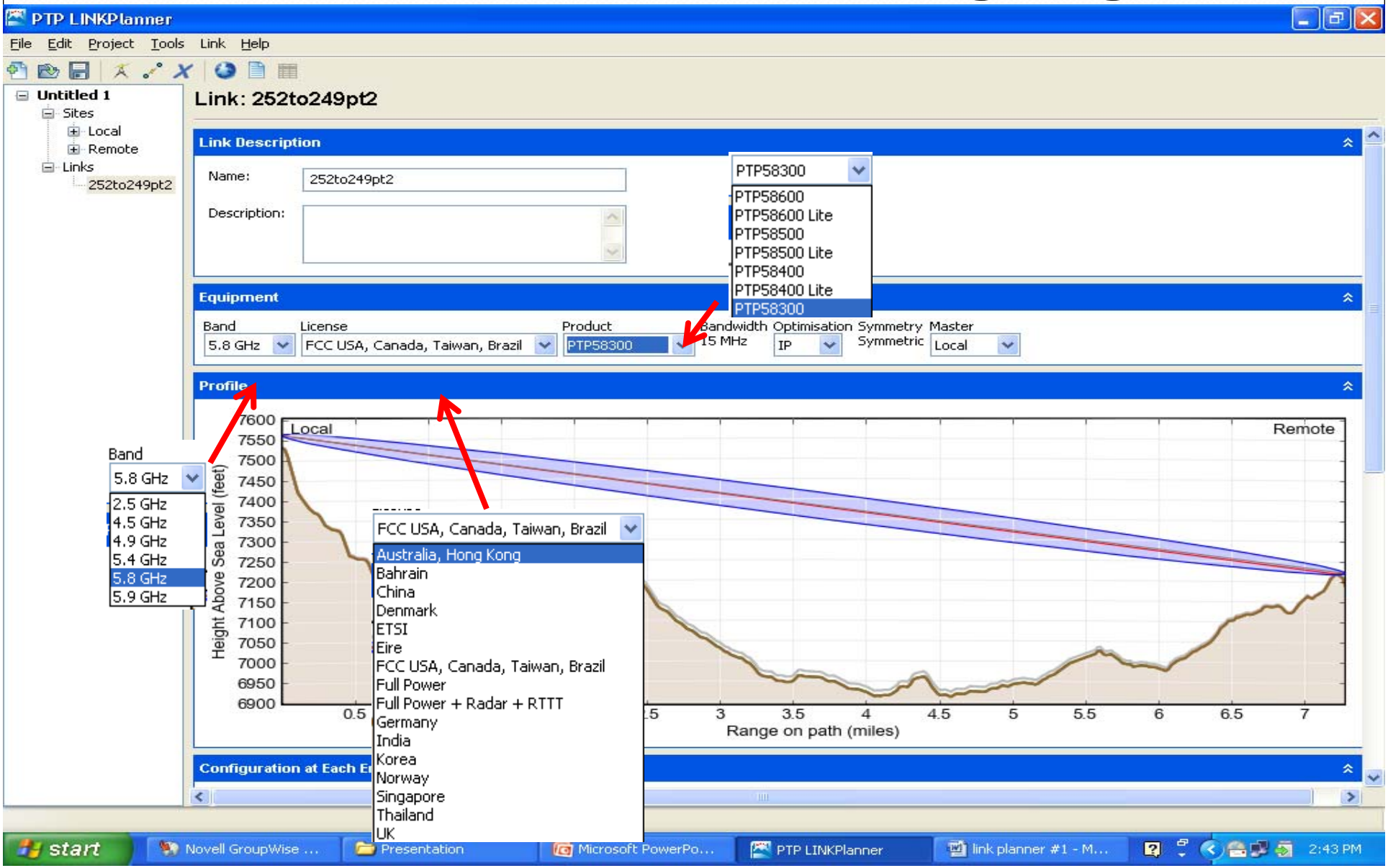
PTP Radio Vendor Selection

- In-house Vendor Research
  - Design assistance inquiries
  - Performance inquiries
  - Reliability/Availability inquiries
  - Support process and availability
  - Products available
- Motorola's Point-to-Point Radio Product Line Selected
  - Proactive on inquiries
  - Defined support process; readily available and accessible
  - Active promotion of "Underbuild Solution" (integration into our licensed 6.0 GHz microwave infrastructure)
  - Highlights used from their PTP Link Planner (5 highlights)
  - Highlights from PTP Link Planner export into Google Earth (2 highlights)

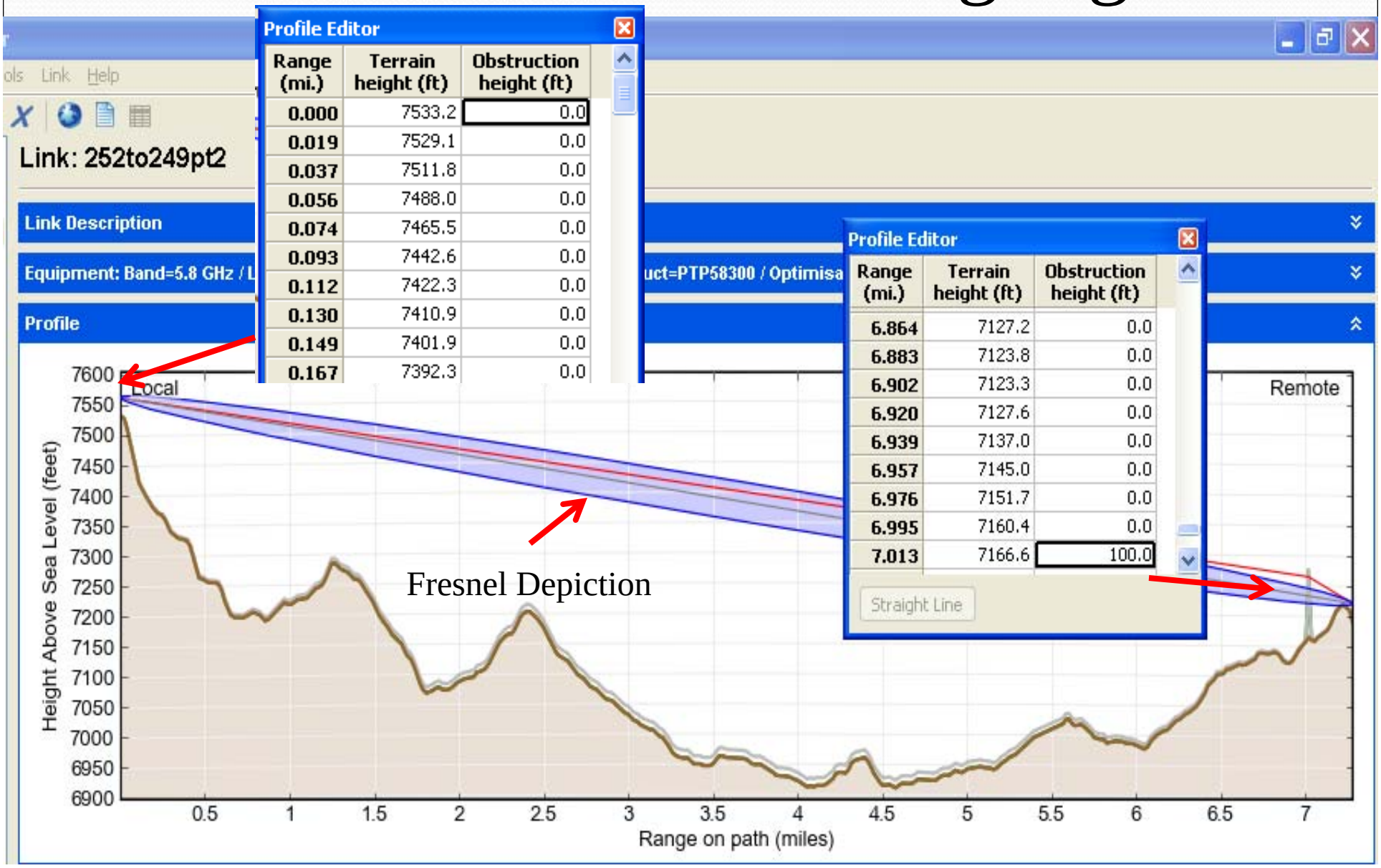
Motorola Link Planner Highlight #1



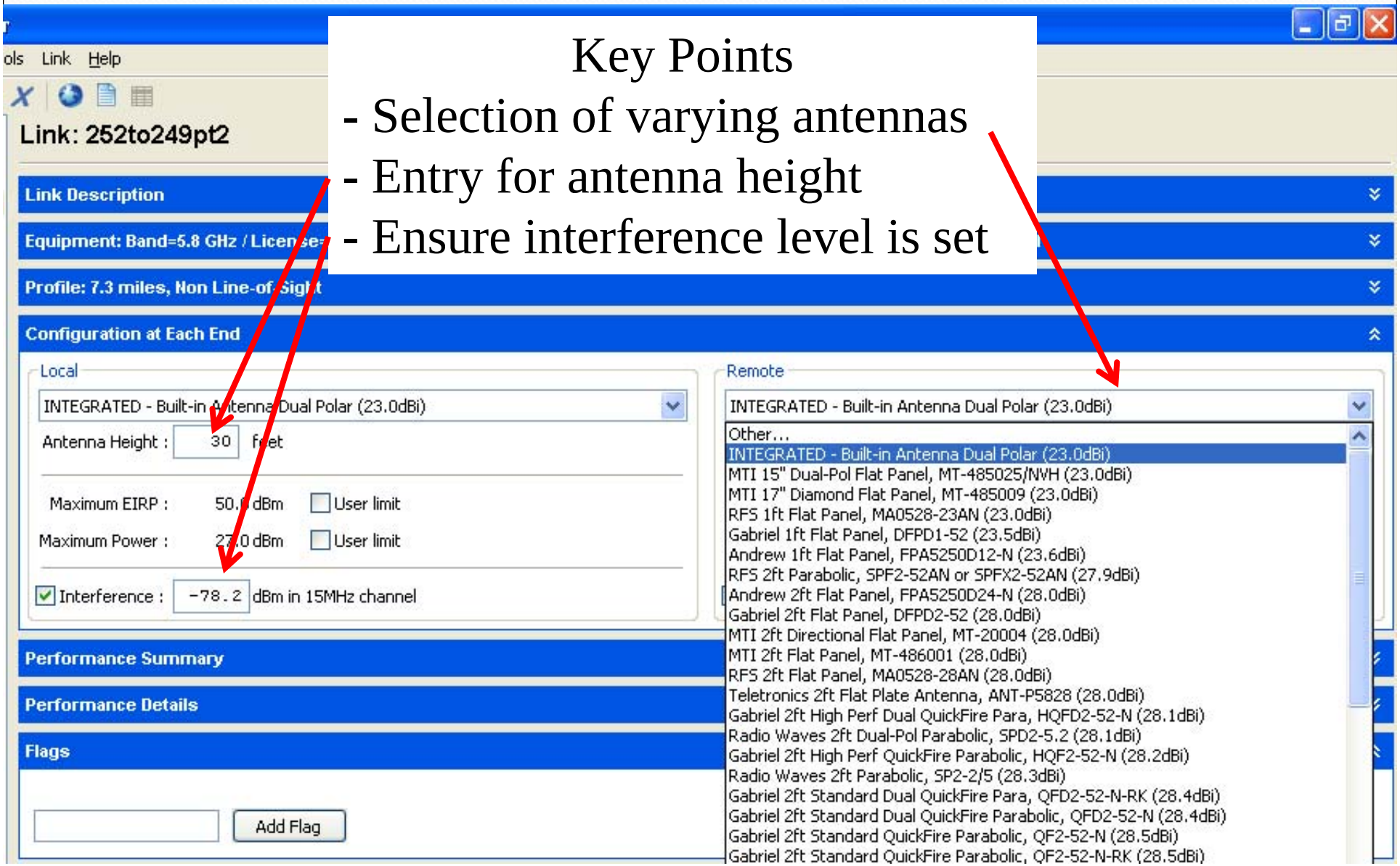
Motorola Link Planner Highlight #2



Motorola Link Planner Highlight #3



Motorola Link Planner Highlight #4



Motorola Link Planner Highlight #5

User inputs (requirements) for both ends

Performance Summary

Throughput to Local

Mean Throughput Predicted :	5.35	Mbps
Mean Throughput Required :	5.0	Mbps
Percentage of Required Throughput :	107	%
Min Throughput Required :	1.0	Mbps
Min Throughput Availability Required :	99.9900	%
Min Throughput Availability Predicted :	99.9999	%

Link Summary

Aggregate Throughput:	**18.14**	**Mbps**
Link Availability:	**99.9999**	**%**
System Gain Margin:	19.35	dB
Free Space Path Loss:	129.07	dB
Excess Path Loss:	1.51	dB
Total Path Loss:	130.57	dB

Throughput to Remote

Mean Throughput Predicted :	12.79	Mbps
Mean Throughput Required :	5.0	Mbps
Percentage of Required Throughput :	256	%
Min Throughput Required :	1.0	Mbps
Min Throughput Availability Required :	99.9900	%
Min Throughput Availability Predicted :	99.9999	%

Performance Details

Common details

Mode:	64QAM	64QAM	16QAM	16QAM	QPSK	64QAM	64QAM	16QAM	16QAM	QPSK	QPSK	BPSK
Code rate:	0.83	0.67	0.75	0.50	0.75	0.83	0.67	0.75	0.50	0.75	0.50	0.50
Payloads:	Dual	Dual	Dual	Dual	Dual	Single	Single	Single	Single	Single	Single	Single
Max Aggregate Throughput (Mbps):	25.57	20.26	15.29	9.96	7.63	12.63	9.96	7.63	4.97	3.64	2.31	0.98
Max Throughput Each Way (Mbps):	12.79	10.13	7.64	4.98	3.81	6.31	4.98	3.81	2.48	1.82	1.16	0.49

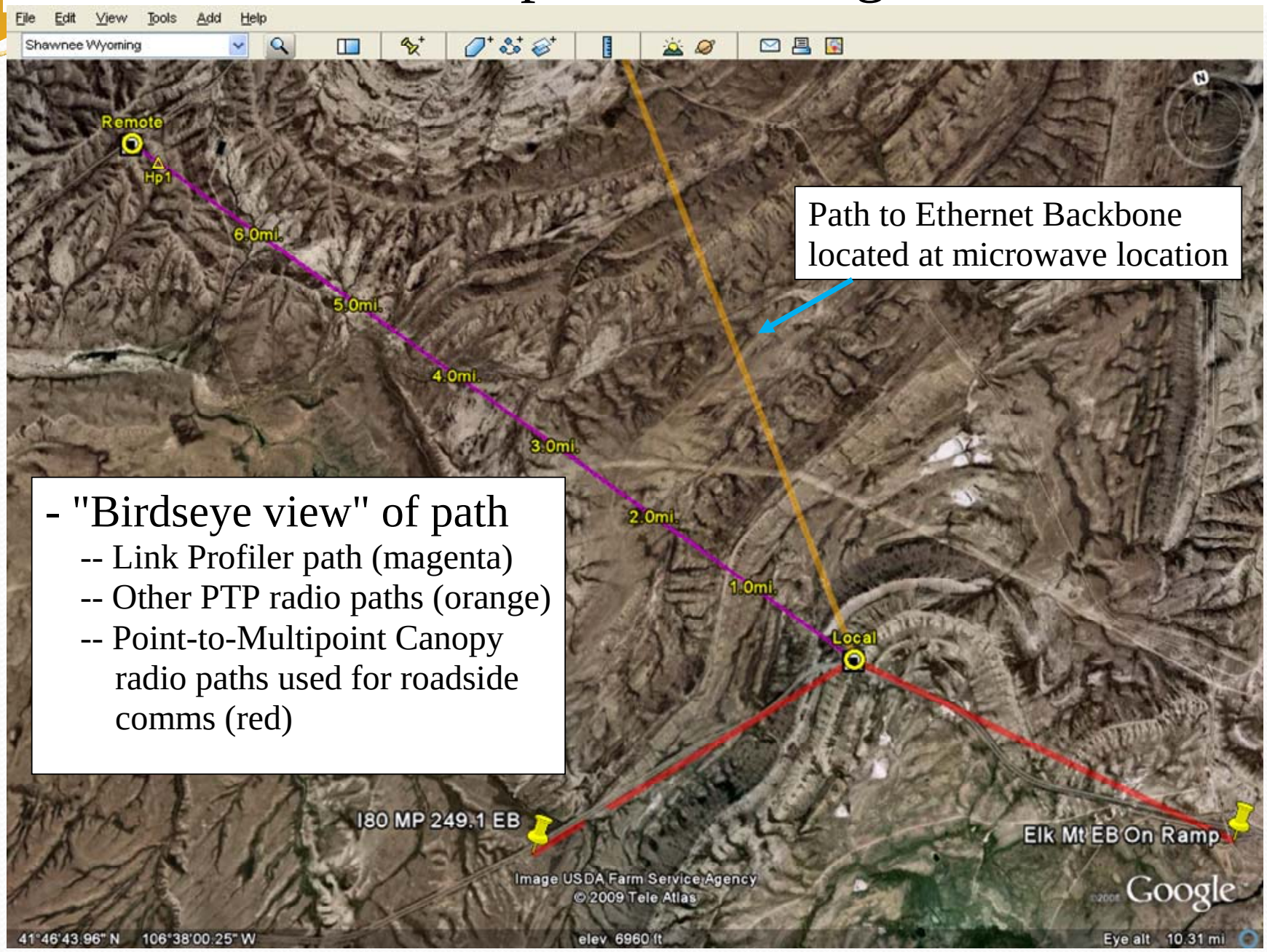
Performance to Local

Fade Margin (dB):	-10.87	-5.56	-1.15	3.67	7.71	-7.39	-2.38	1.94	6.71	10.74	13.21	19.35
Mode Availability (%):	0.0000	0.0012	14.3004	99.1808	99.9975	0.0000	0.0000	0.0014	0.0014	99.9999	99.9999	99.9999
Receive time in Mode (%):	0.0000	0.0012	14.2992	84.8805	0.8167	0.0000	0.0000	0.0014	0.0000	0.0010	0.0001	0.0000

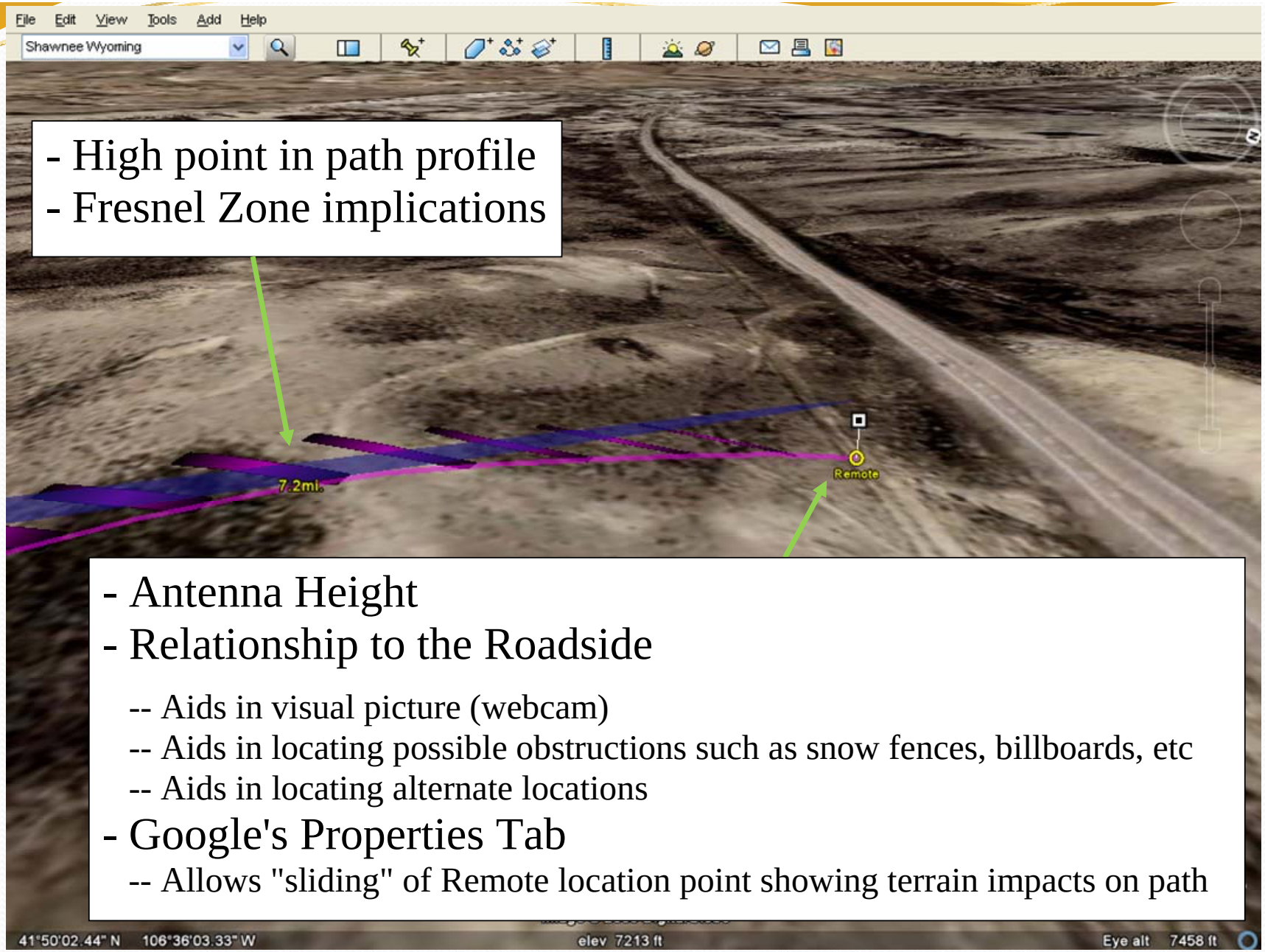
Performance to Remote

Fade Margin (dB):	7.02	12.32	16.74	21.56	25.60	10.49	15.51	19.83	24.60	28.63	31.10	37.23
Mode Availability (%):	99.9961	99.9985	99.9986	99.9986	99.9986	0.0014	0.0014	0.0014	0.0014	99.9999	99.9999	99.9999
Receive time in Mode (%):	99.9961	0.0024	0.0000	0.0000	0.0000	0.0014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Link Planner Export into Google Earth, #1



Link Planner Export into Google Earth, #2



PTP Radio Considerations

- Integrated
  - Radio electronics and antenna all one unit
  - Minimal footprint on tower (14” x 14” flat panel antenna)
  - Minimal footprint within support building (2”x4”x6” surge suppressor and 1”x3”x10” power unit)
  - Radio output and antenna gain becomes limiting factor towards bandwidth capacity based on the “worst link path profile”
  - Tower time required for installation/maintenance exterior radio mount
  - Harsh environmental conditions for exterior radio mount
- Connectorized
  - Radio electronics and use of external antenna
  - Footprint on tower varies depending on antenna size
  - Similar footprint within support building as with exterior radio mount
  - Tower time required for installation/maintenance exterior radio mount
  - Harsh environmental conditions for exterior radio mount

PTP Radio Considerations

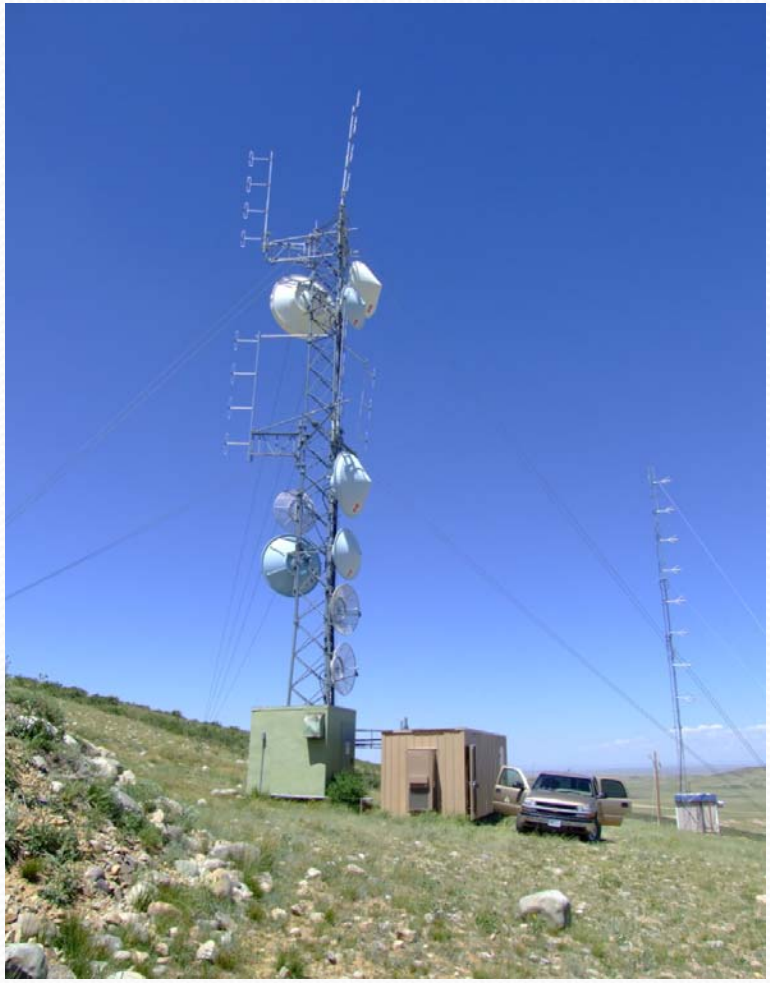
(continued)

- Underbuild Solution
  - Uses connectorized version of radio and integrates into microwave's "plumbing" at the transition junction
  - Radio electronics moved inside out of harsher environment
  - No additional tower footprint (uses microwave dishes)
  - Minimal increase of footprint within support building (12" x 12" radio)
  - Bandwidth capacity based radio output and microwave dish gain
  - No tower time required for installation/maintenance
  - Additional effort/expense of passive filters and circulators for integration into microwave "plumbing"
- Limiting Factors
  - Funds available (approximately $109K, excludes labor costs)
  - Self-imposed (avoid use of microwave "transmit side")

PTP Radio Considerations

(Limiting Factors continued)

- Tower Space
  - -- Physical dish/antenna locations limited
  - -- Tower loading factor at/near maximum limits
  - -- Example site is a self-support tower with guy wires



PTP Radio Considerations

(Limiting Factors continued)

- Support Building

-- Limited rack room

PTP Radio Considerations

(continued)

- Selected Hybridized Underbuild Solution
  - Similar configuration as Underbuild Solution
  - Existing microwave uses A-dish for Transmit/Receive and B-dish for Spatial Diversity Receive Only
  - Passive filters not required for use of microwave's receive only dish
  - Bandwidth capacity limited to calculations based on radio output and B-dish gain
- Selected Motorola's PTP400 Radio
  - 5.8 GHz and connectorized variant use in the underbuild solution
  - Lite model with capability to upgrade capacity upgrade via software

Concept of Operations Highlights
(ConOps)

- Drafted in parallel to backbone design
  - Capture consensus and approval of project
  - Capture commitment to what, when and by whom things are done
  - No commitment to what could not be done
- General Guidelines
  - Document approval
  - Modifications
- Stakeholders and Responsibilities
  - IT, ITS and Telecom
  - Process for future stakeholders
- Basic requirements Identification
  - Capacity
  - Path Route and Layout

ConOps Highlights
(continued)

- Basic Requirements Identification (continued)
  - Latency (backbone start to finish; no end devices)
  - Availability (99.9% uptime rate, excluding maintenance downtimes)
  - Security
- Support
  - Network Administration (Telecom for radios, IT for routers/network)
  - Organization (Telecom at remote sites to include remove/replacement of routers)
  - Vendor
- Operational Scenarios
  - Routine monitoring
  - Outage reporting
  - Response and repair priorities

“Sizing the Pipe”

- Bandwidth Categories
  - Used Low, Medium and High categories for devices
  - Comparable area DSL for Remote Maintenance shops
- Count, Categorization and Calculation
  - Wyoming’s ITS Statewide Architecture Report (I-80)
  - Remote Maintenance Shops
  - Assumption used: “100% demand: all devices all locations”
- Future Considerations
  - Expansion to include ITS devices beyond I-80
  - Flexibility and Expansion
- Latency

“Sizing the Pipe”

Bandwidth Categories

- Low Bandwidth: 9.6Kbps
  - Generally recognized and accepted as “low”
  - Conservative value: many devices are much lower
- Medium Bandwidth: 50Kbps
  - Main derivative was Webcam snapshot file size
- Comparable area DSL: 512Kbps
- High Bandwidth: 1.5Mbps
  - Recognizable as “T-1” capacity
  - Previous Streaming Video used T-1 circuits
  - Consensus of 1.5Mbps for video streaming (streaming example)

“Sizing the Pipe”

Count, Categorization and Calculation

- Area
  - ITS Devices on or in immediate vicinity of Interstate 80 (two WYDOT Districts & roughly 400 road miles)
  - Remote Maintenance shops with inadequate commercial services
- High Bandwidth (1.5Mbps)
  - Consensus of one streaming video any one location at any one time
- Comparable area DSL (512Kbps)
  - 4 remote Maintenance Shops
- Medium Bandwidth (50 Kbps)
  - Locations with webcams (webcam snapshots)
  - Rest Areas Kiosks (information posting, no Internet Access)
  - Portable Traffic Management Stations (webcam snapshots)
  - Total count: 79

“Sizing the Pipe”

Count, Categorization and Calculation

- Low Bandwidth (9.6 Kbps)
  - RWIS, DMS, PDMS, HAR, RC, FB, VSL, SS
  - Total Count: 81
- Calculation
  - 1 x 1.5Mbps = 1.5Mbps
  - 4 x 512Kbps = 2084Kbps
  - 79 x 50Kbps = 3950Kbps
  - 81 x 9.6Kbps = 778Kbps
  - “100% demand: all devices all locations”
- Target for sizing: 8.3Mbps

“Sizing the Pipe”

Future Considerations

- Repeat sizing process for device loading beyond I-80
  - Medium bandwidth category: 10 count
  - Low bandwidth category: 82 count
  - Additional loading: 1.3Mbps
- Used “Double Swag” for growth in the immediate future; 3 years
- Future target for sizing: 19.2Mbps
- Latency
  - From beginning to end of I-80 backbone (end devices not included)
  - 250 milliseconds or less

PTP Radio Model Selection

- Motorola's PTP400 Model
- 5.8 GHz band to fit underbuild solution
- Connectorized to fit into underbuild solution
- Lite model
  - Met initial capacity target
  - Upgradeable to Full model via software doubling capacity
- AES available via software upgrade
- Fit with available funds

Power Considerations

- One standard model
- Equipment requirements varied
  - PTP Backhaul radios: 48 VDC or 120 VAC
  - Canopy Equipment: 24 VDC or 120 VAC
  - Router: 120 VAC only
- Power at remote locations
  - Commercial power
  - Standby diesel generator power
  - 48 VDC site battery system

Power Selection

- Selected use of 48 VDC to 120 VAC Inverter
  - Sized for maximum installation/operational scenario
    - 6 PTP Radios
    - 2 routers
    - 6 Canopy Radios/CMM
    - Doubling factor
  - 1500 Watts
  - 1u size, space considerations
  - 95% efficiency, true sine wave output
  - N+1 parallel operation for capacity or redundancy
  - Microprocessor, programmable features
- Inverter selected was Onyx S548-120

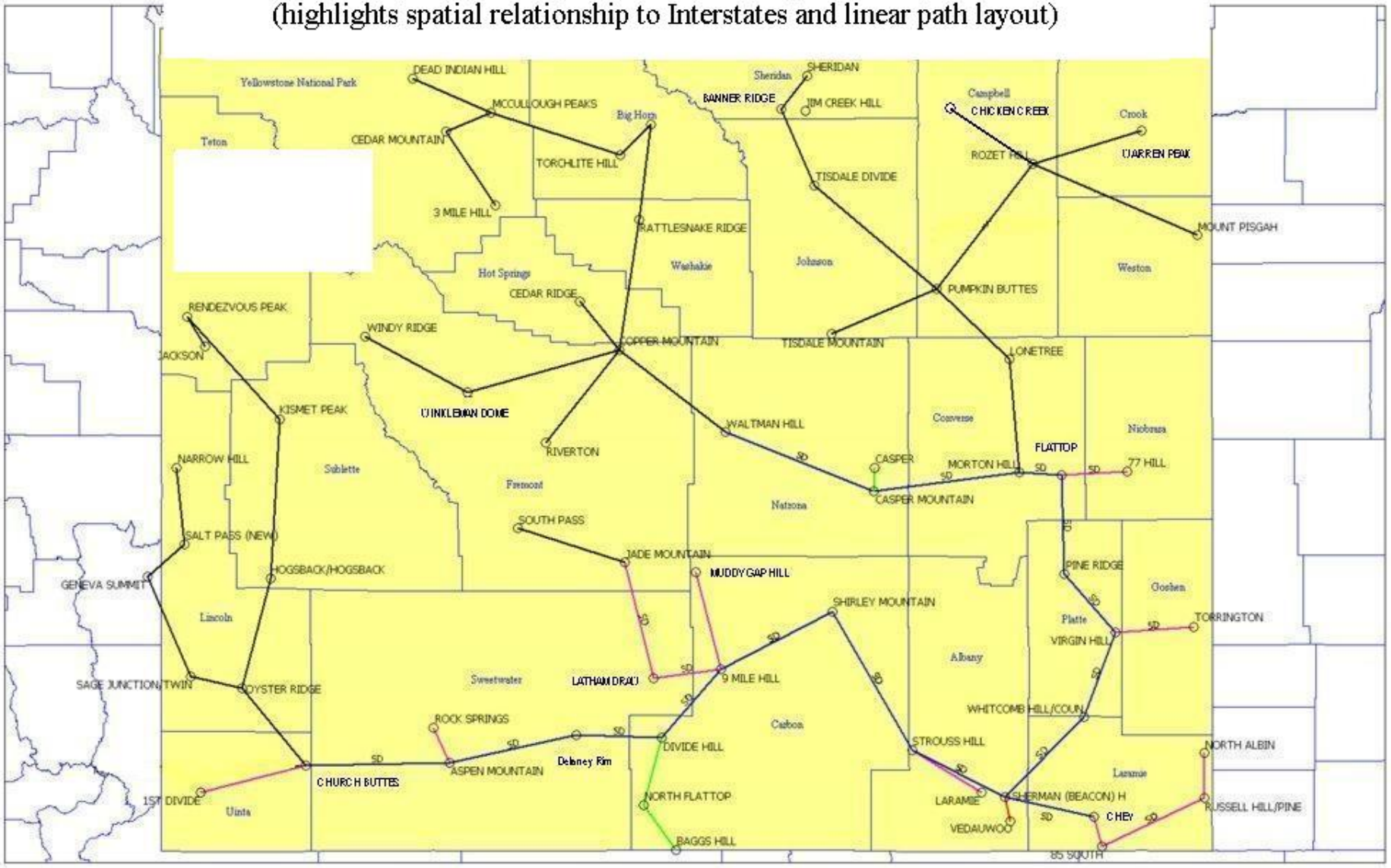
Router Selection

- One standard model
- Hardware
  - Two FE ports for PTP radio in each direction
  - Modular slot for additional ports
  - Modular slot for commercial services options
- Routing Protocols and QOS
- Cost and Size
- Significant factor in selection was IT Program
  - Use of Cisco products is standard
  - Training and familiarization minimal
  - Product support contract in place
- Cisco 1841 Integrated Services Modular Router

“Laying out Pipe Path”

- Use existing microwave path(s)
- Extending into each District headquarters/Alternate TMC
- Establishing an alternate route(s) due to “linear” microwave path
- If possible, extend to existing locations where IT Network being used for mission systems transport
- Future expansion covering I-25 and I-90

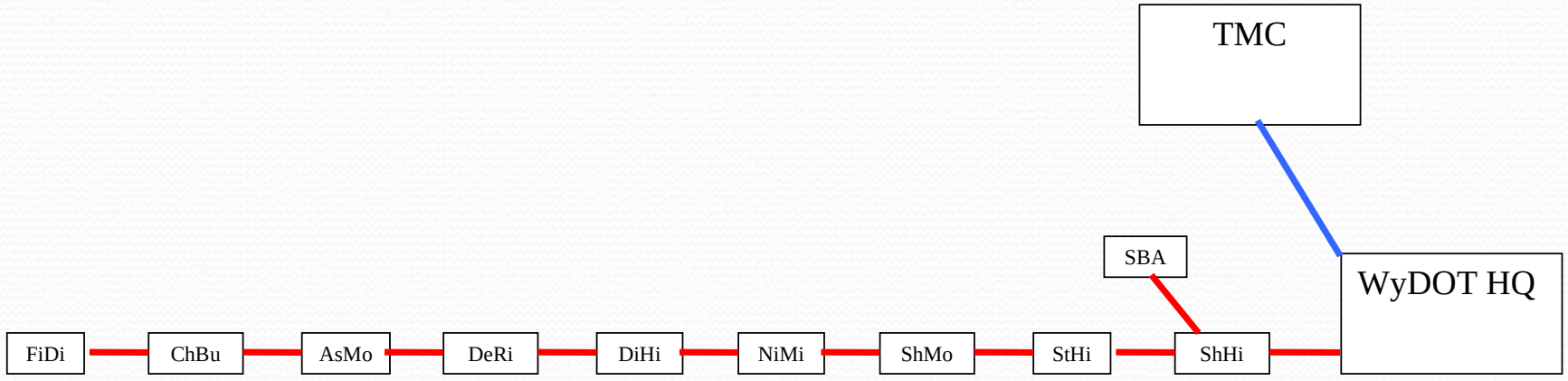
State of Wyoming's Original Microwave Migration Proposal Plan
(highlights spatial relationship to Interstates and linear path layout)



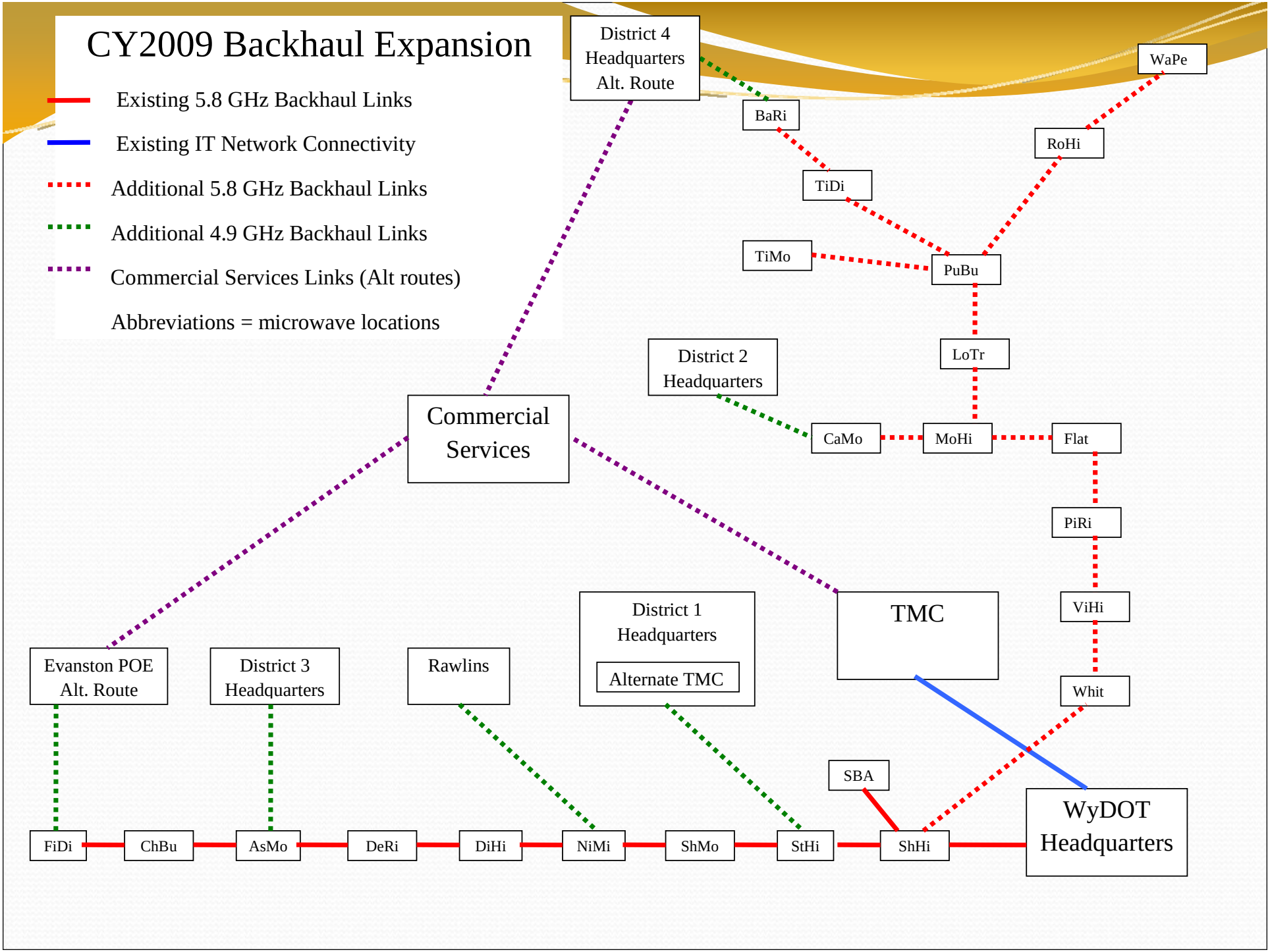
Existing Backhaul Deployment

- 5.8 GHz Backhaul Links
- IT Network Connectivity

Abbreviations = microwave locations



CY2009 Backhaul Expansion

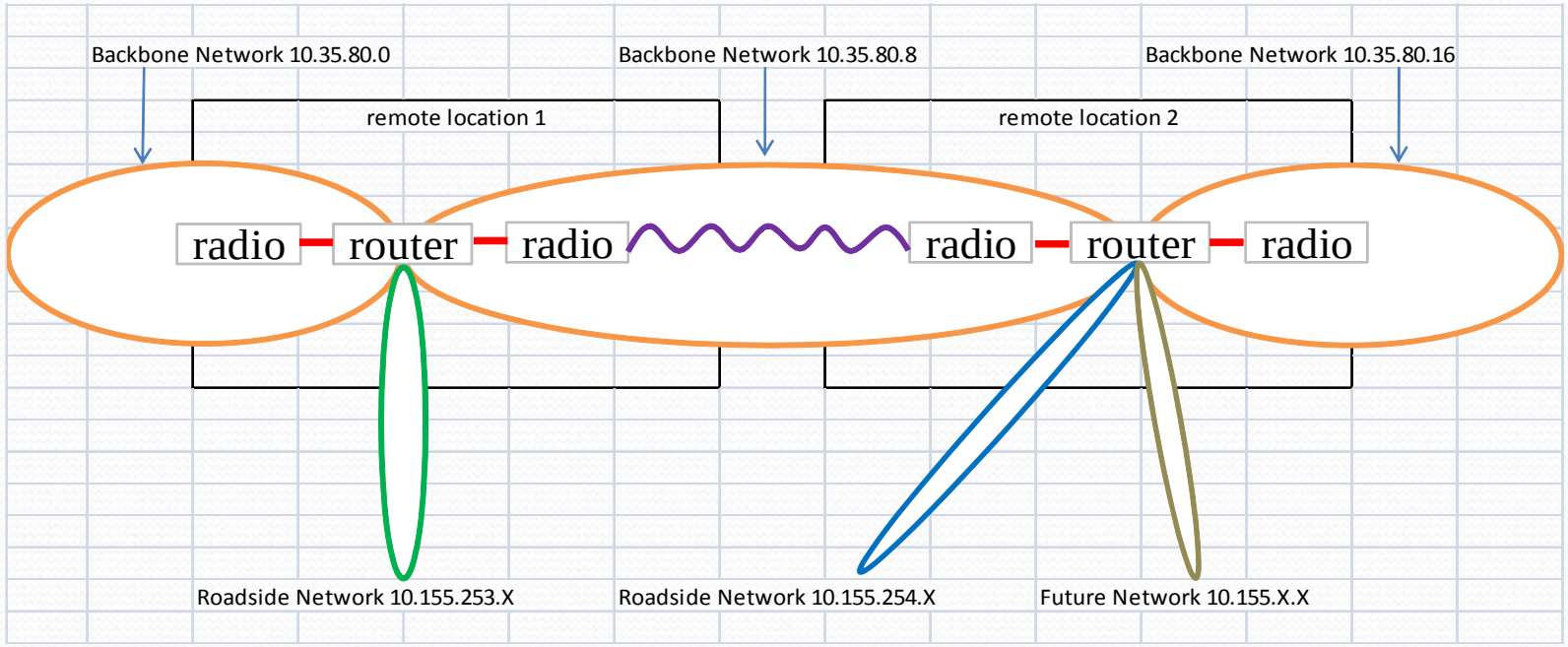


Network Configuration

- Backbone Network
  - I80 backbone on its own class C network (no other devices)
  - Use individual subnets between remote locations
  - Network is “on the outside” (has to pass through the Firewall)
  - IP assignment controlled by IT
- Roadside Network
  - One class C network assigned at each remote location
  - Current networks are ITS and they control IP assignments
  - Telecom devices serving roadside devices are included within network being served
  - Future networks could be added to serve other mission systems

Network Configuration

(continued)



Installation Highs

- Uptime rate of Backbone was 100%
- Completed in time to provide backhaul comms for large ITS projects
- Installation cost at $104K – within funds available
- Stakeholder acceptance better than expected
- Radios performance excellent – met ConOps objectives
  - Capacity achieved was a stable 17.5 Mb with one exception
  - Latency was less than 85 ms

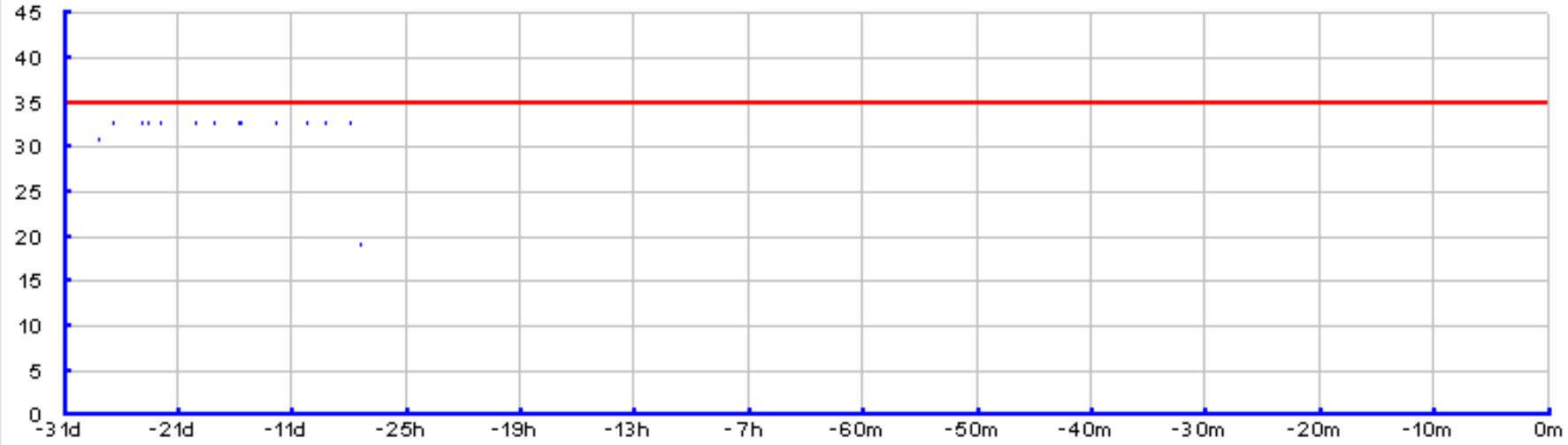
Installation Highs

(Radio performance: capacity)

Diagnostic Plotter

The plot displays three traces. Maximum values are displayed in red, mean values are displayed in purple and minimum values are displayed in blue.

Attributes	Value	Units
Diagnostics Selector	Aggregate Data Rate	

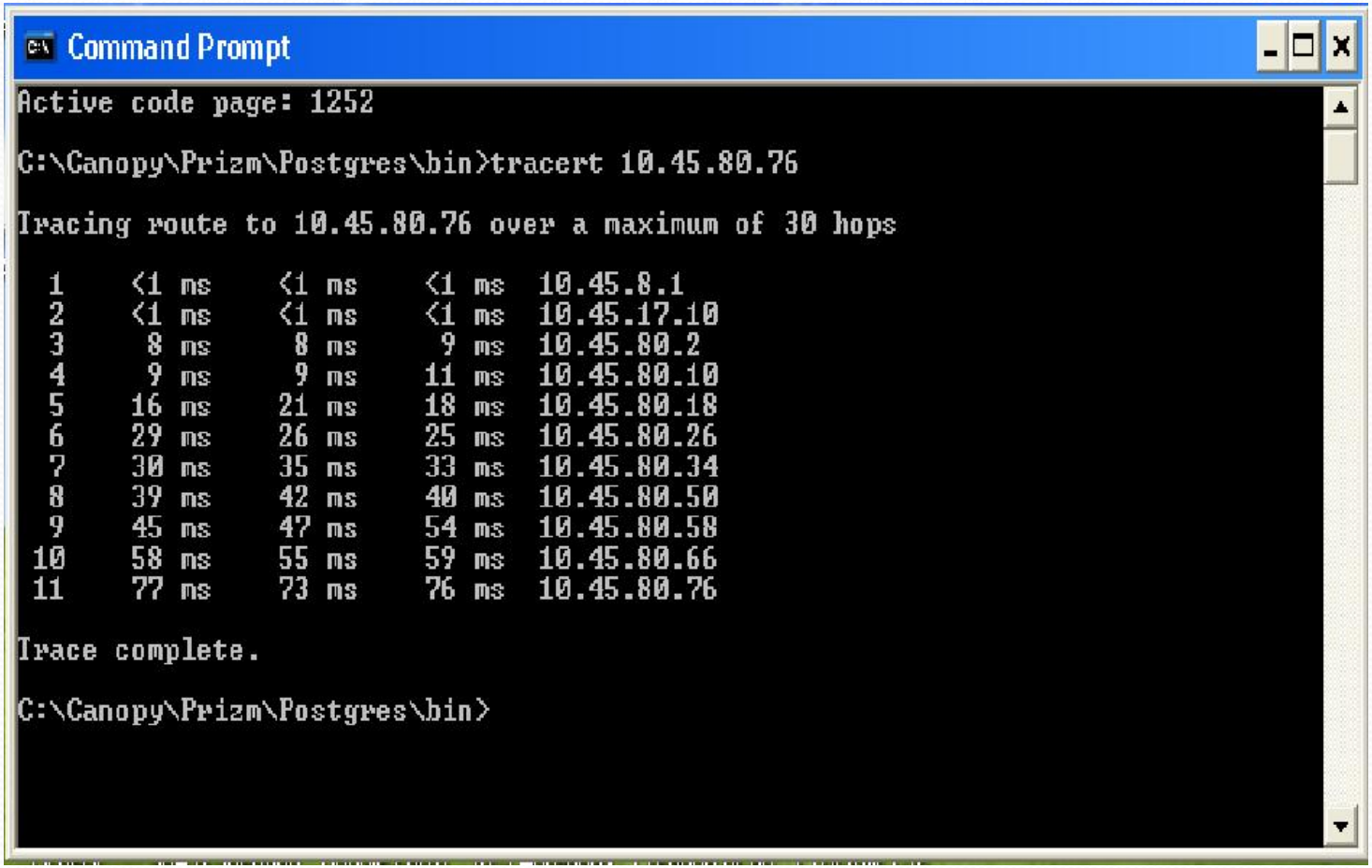


Aggregate Data Rate	35.06,	35.06,	35.06,	35.06	Mbps
Trace Selection	☑ Max	☑ Mean	☑ Min		
Page Refresh Period	3600				Seconds

Plot Selected Diagnostic

Installation Highs

(Radio performance: latency)



Installation Lows

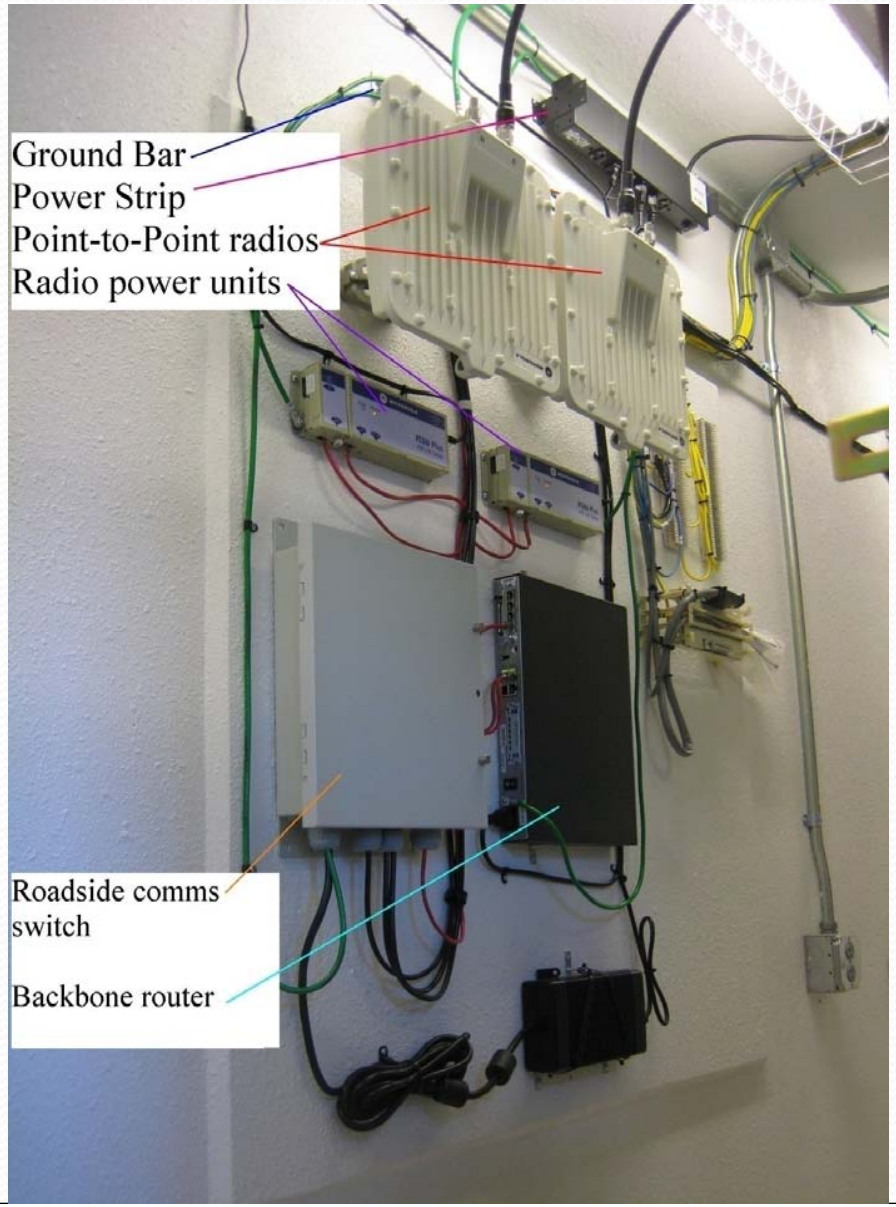
- ARP Cache and roadside device bridge entry mismatch
  - Roadside devices weren't set at or above what routers were set at
  - Roadside comms connectivity lost randomly
  - Problem grew over time as build out progressed and number of roadside devices increased
  - Required re-configuration of all roadside comms devices
- Required movement of some microwave waveguide transitions
- One link turned out to be near-line-of-sight
  - Capacity reduced to 5Mb
  - Scheduled for improvement next phase of backbone construction

Installation Lows

(continued)

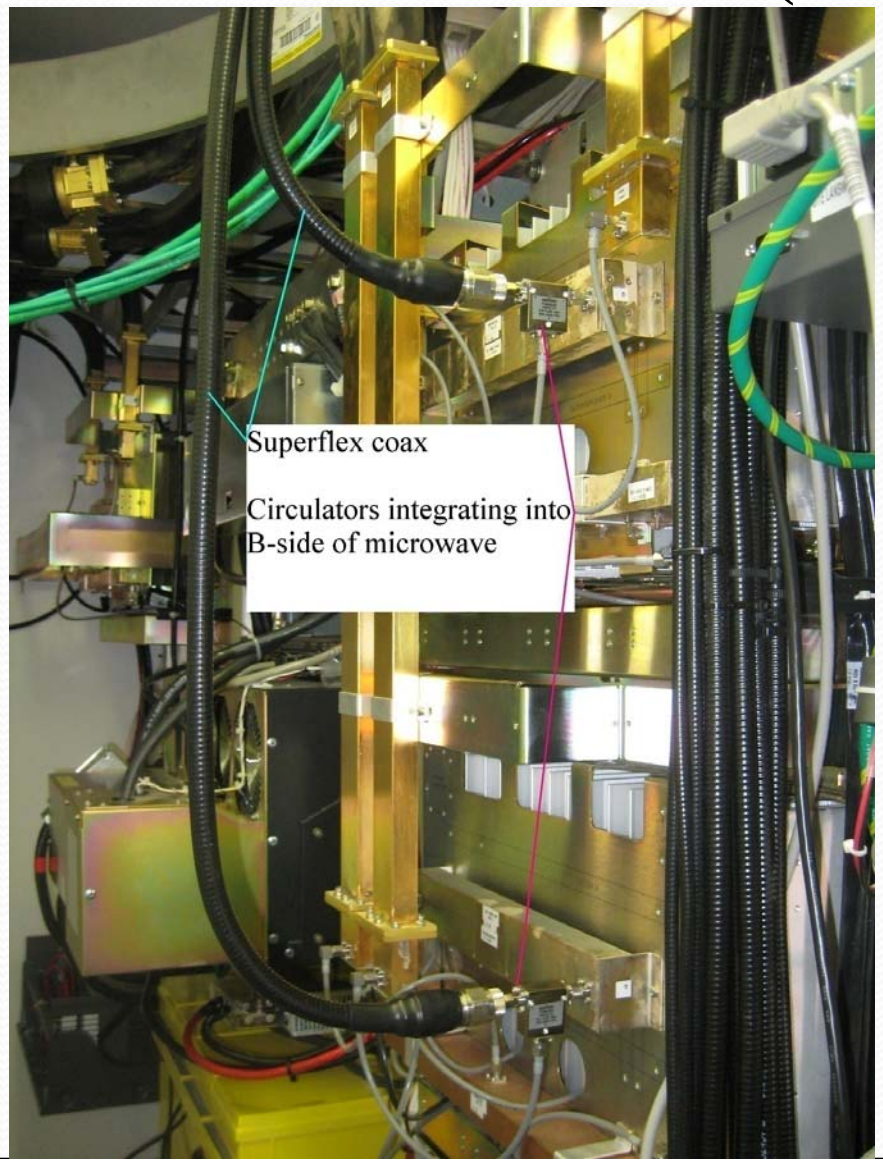
- More time and resources required than anticipated for operation and maintenance of radios
  - Impacted by personnel shortage and other construction commitments
  - Arrangement between sections within the program used to bridge the gap
- PTP400 Radios retired as project neared completion
  - Required faster than planned spares acquisition
  - Required new planning/adaptation to new PTP product line

Installation Pictures



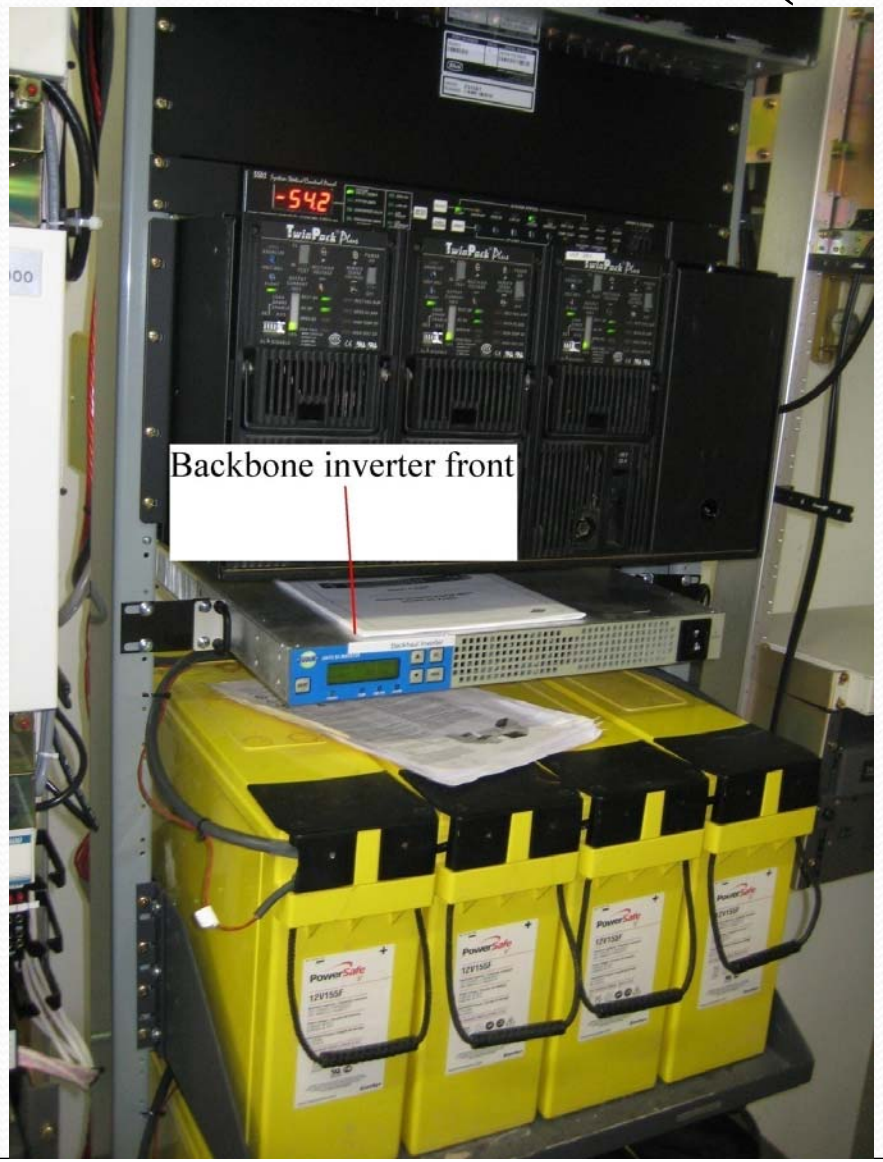
Installation Pictures

(continued)



Installation Pictures

(continued)

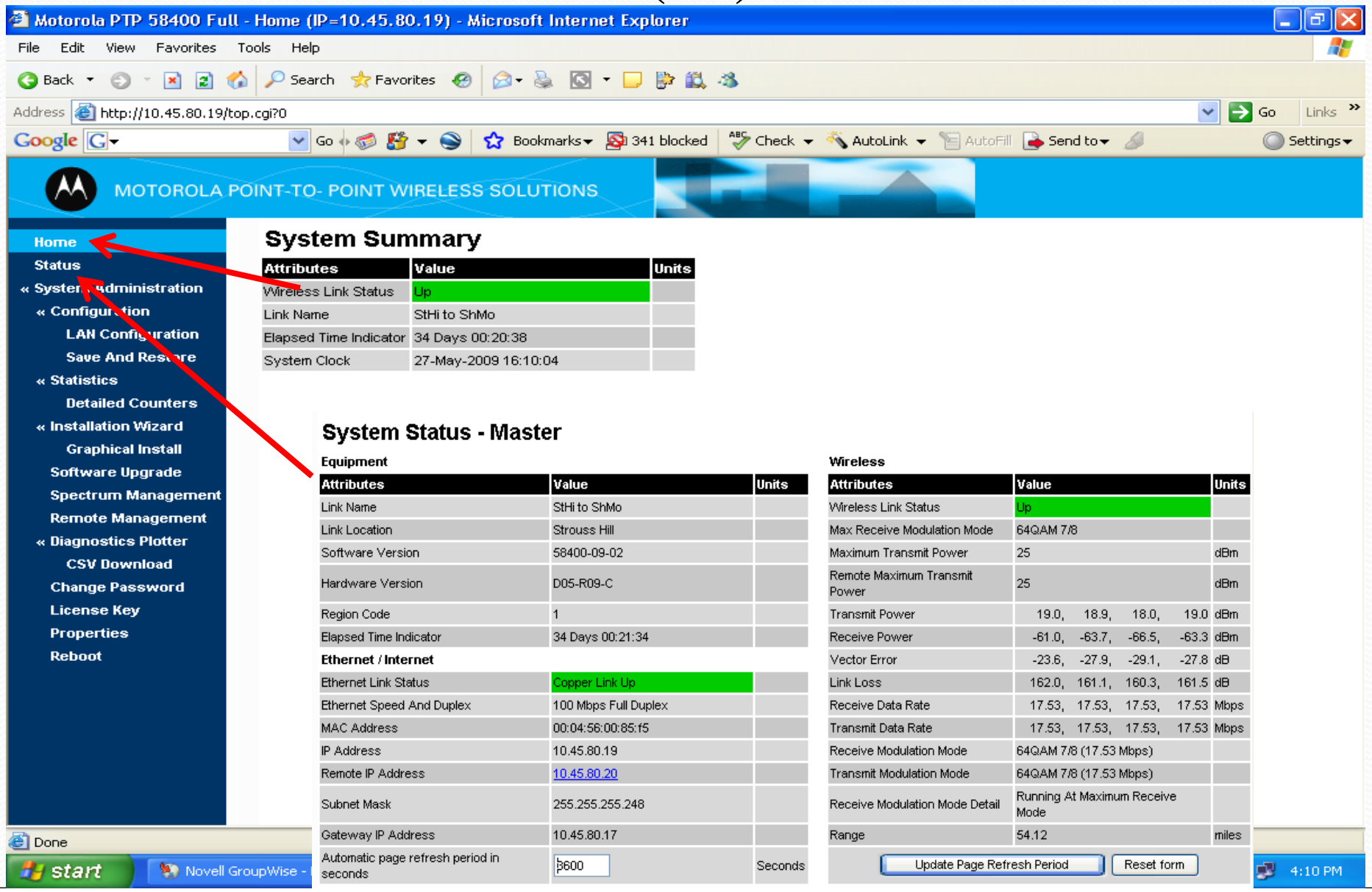


Radio Feature Highlights

- Graphical User Interface (1 highlight)
- Spectrum Management
  - Dynamic Frequency Selection: iDFS (2 highlights)
  - Radio collocation footprint (1 highlight)
- Dynamic adaptive modulation (2 highlights)
- Remote Management (1 highlight)
- Diagnostic Plotter (1 highlight)
  - Vector Error (1 highlight)
  - Data rates (2 highlights)
  - Signal Strength Ratio (1 highlight)
  - Plots are also available in a spreadsheet format

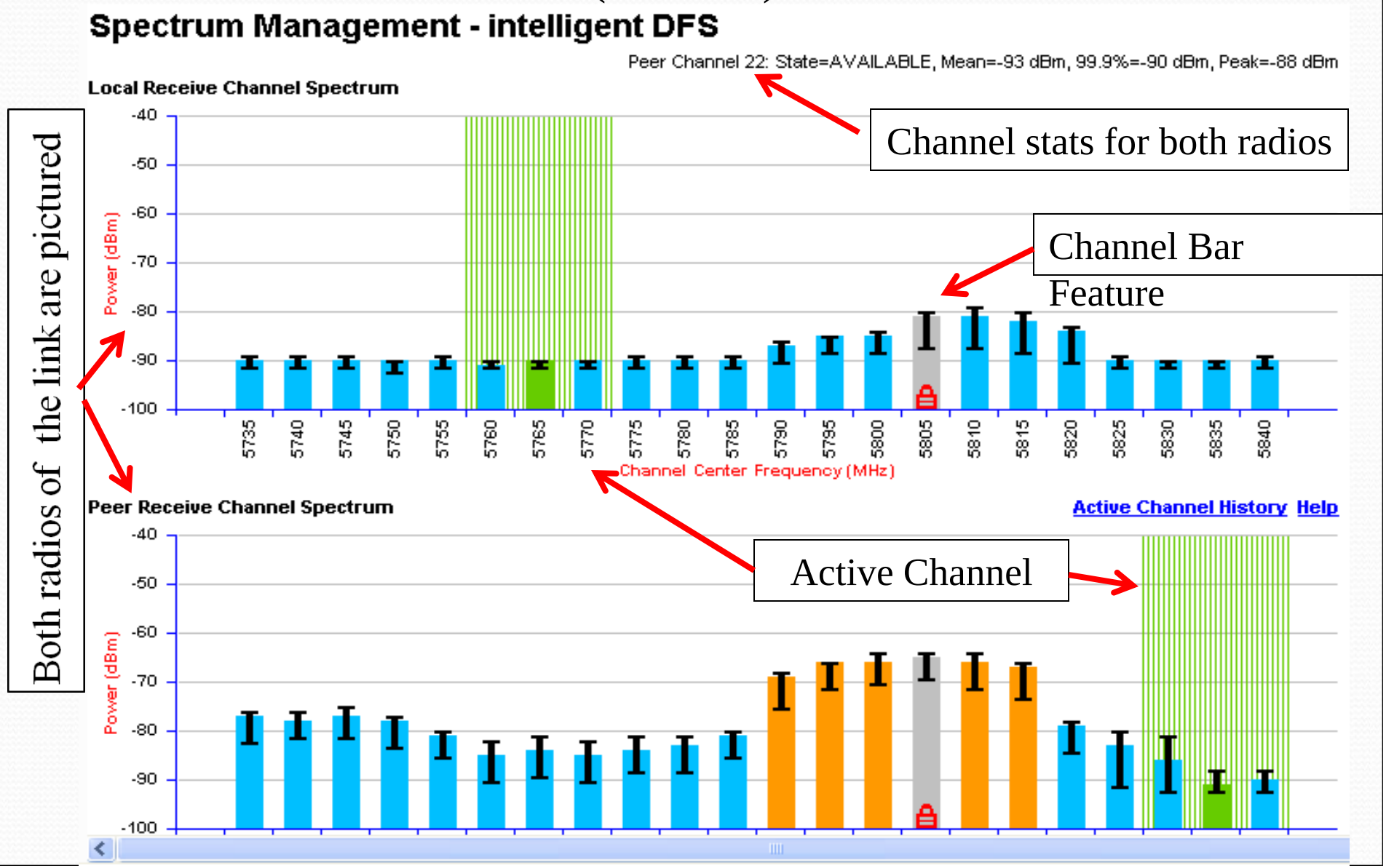
Radio Feature Highlights

(GUI)



Radio Feature Highlights

(iDFS #1)



Radio Feature Highlights

(iDFS #2)

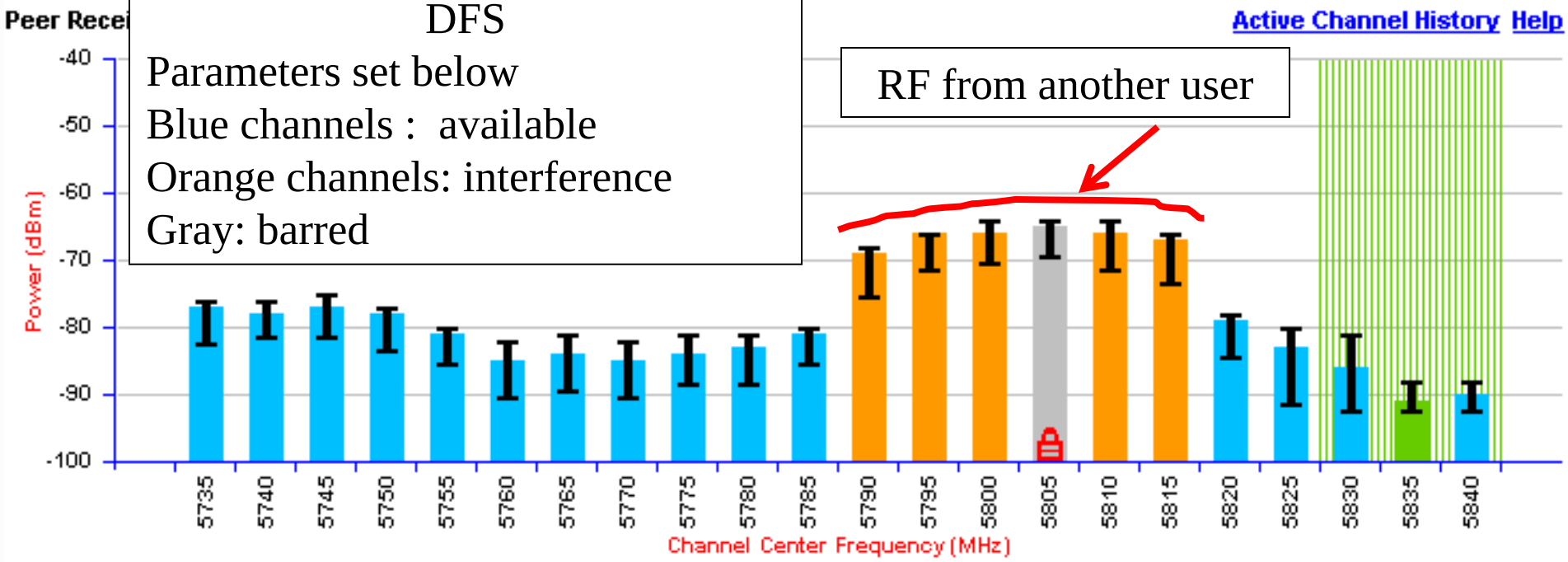
DFS

Parameters set below

Blue channels : available

Orange channels: interference

Gray: barred

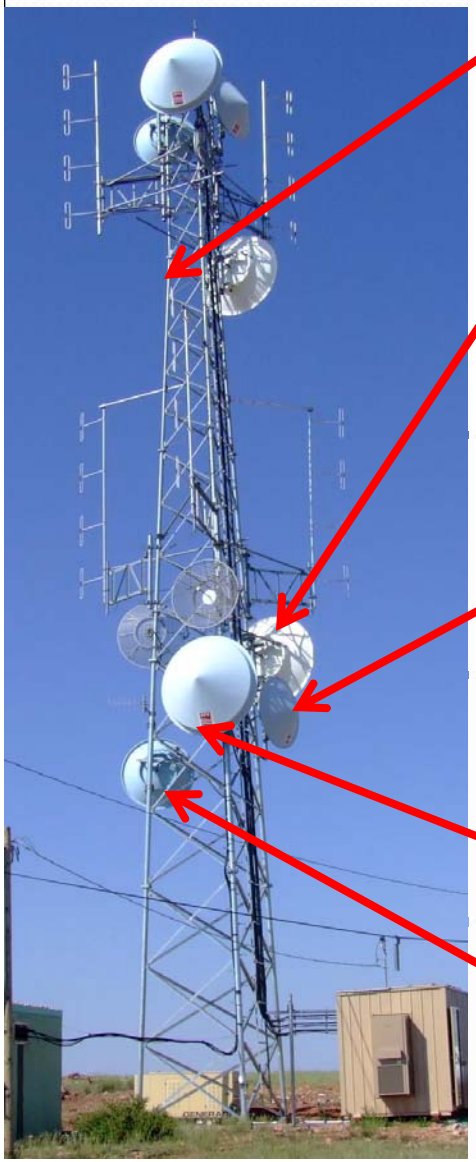


Attributes	Value	Units
Spectrum Management Page Refresh Period	60	Seconds
Hopping Margin	3	dB
Hopping Period	180	Seconds
Hopping Counter	5 (+0)	

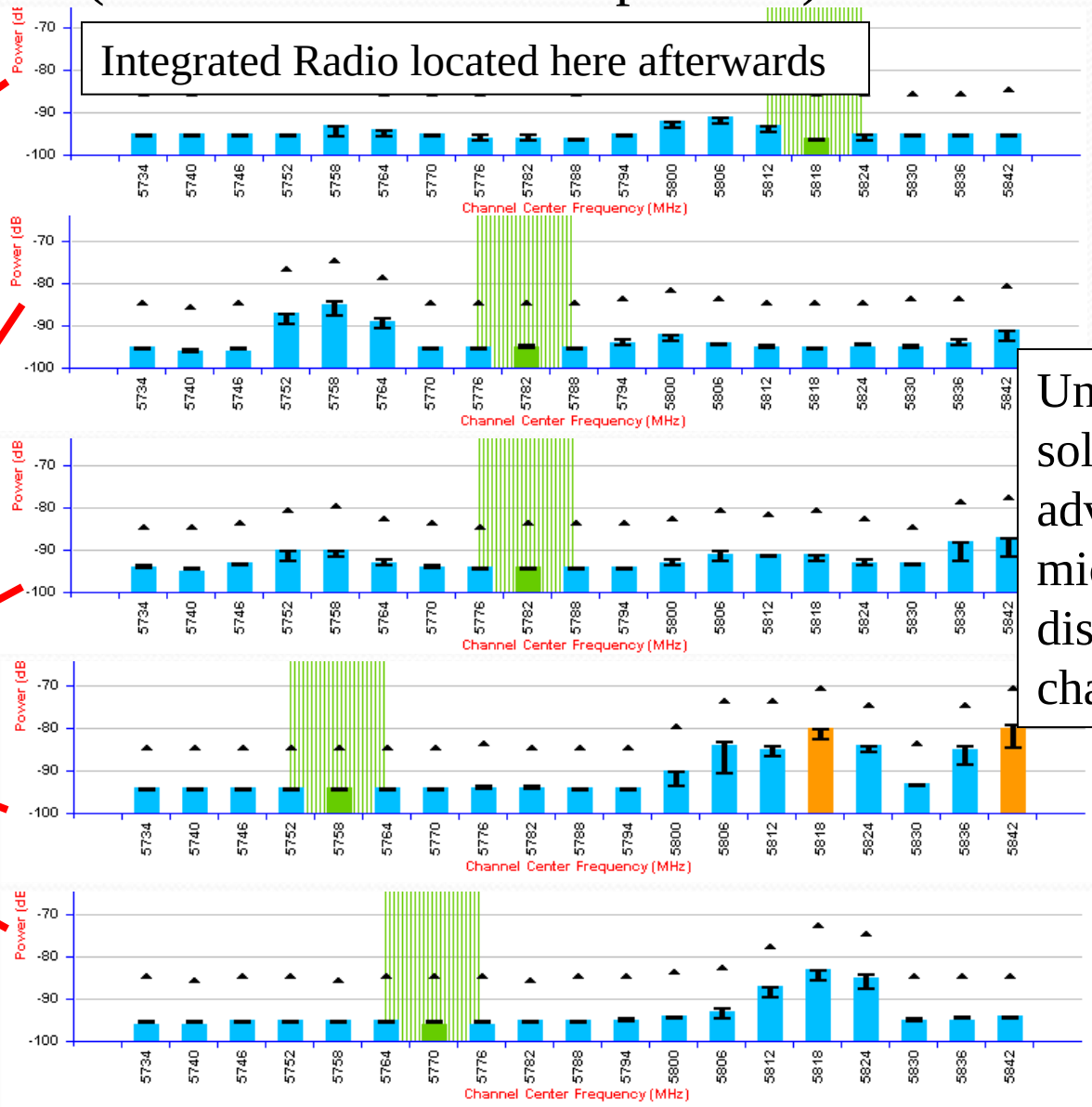
Attributes	Value	Units
Interference Threshold	-70	dBm
Asymmetric DFS	Disabled / Enabled	
Channel Bandwidth	15	MHz
Submit configuration changes	Reset form	

Radio Feature Highlights

(radio collocation footprint #1)



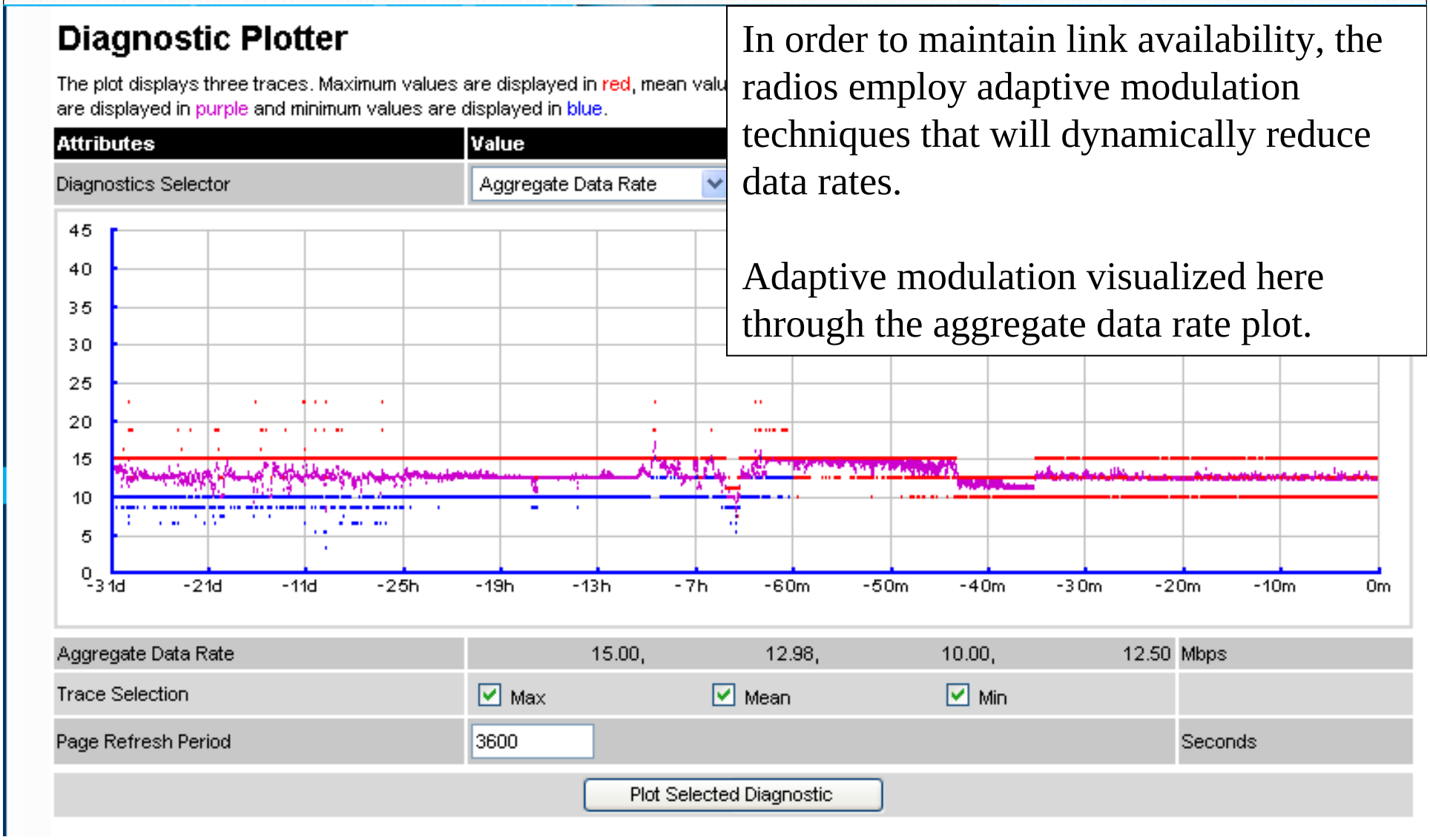
Integrated Radio located here afterwards



Underbuild solution takes advantage of microwave dish isolation characteristics

Radio Feature Highlights

(Dynamic Adaptive Modulation #1)

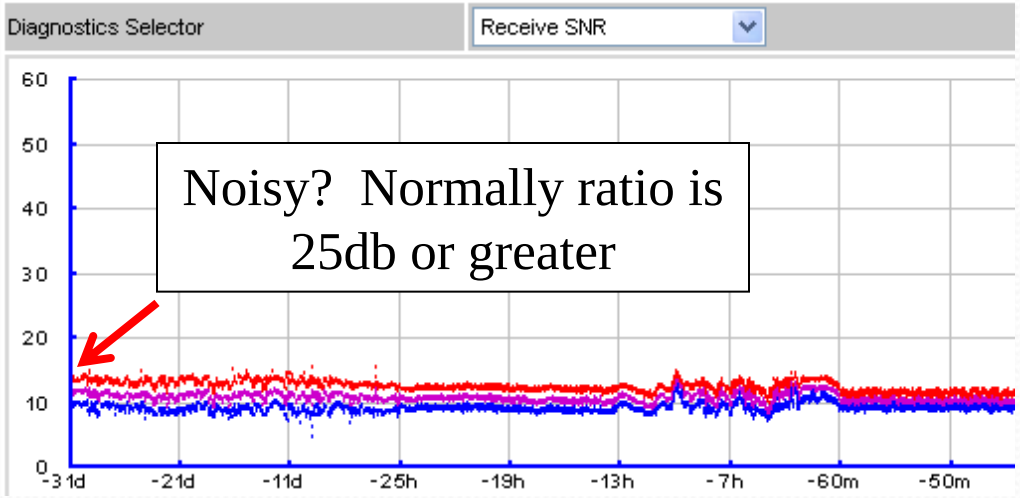


In order to maintain link availability, the radios employ adaptive modulation techniques that will dynamically reduce data rates.

Adaptive modulation visualized here through the aggregate data rate plot.

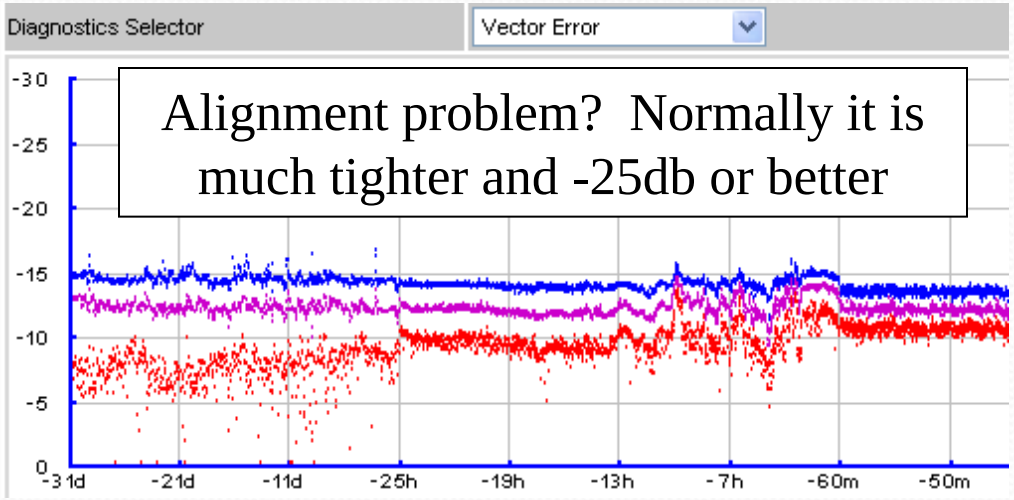
Radio Feature Highlights

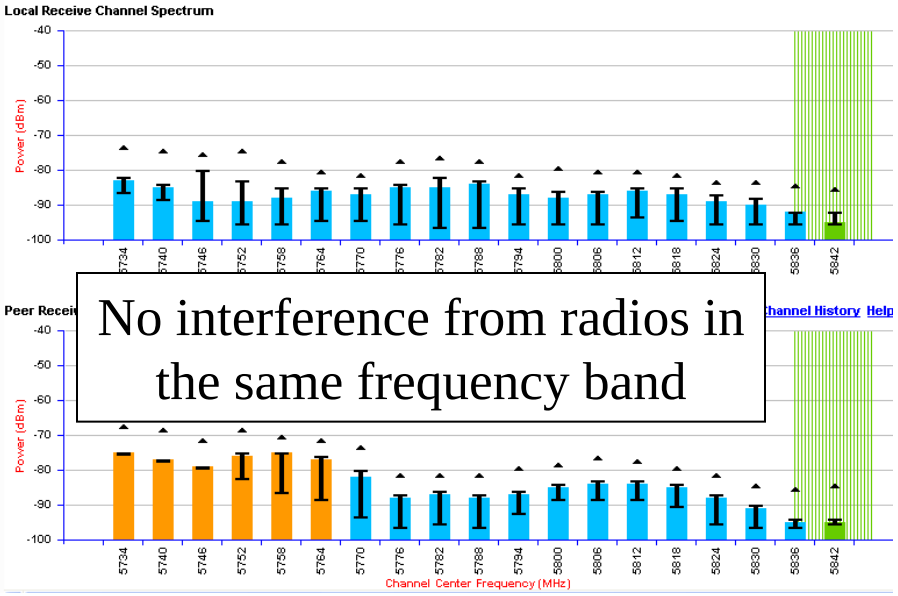
(Dynamic Adaptive Modulation #2)



Path propagation, interference and other adverse conditions are taken into account when employed.

Other tools from same radio in previous slide can be used to locate possible sources for the adaptive changes that are occurring.





Radio Feature Highlights

(Remote Management)

Remote Management

HTTP and Telnet

Attributes	Value	Units
HTTP Access Enabled	○ No ◉ Yes	
Telnet Access Enabled	○ No ◉ Yes	

Simple Network Management Protocol (SNMP)

SNMP State	○ Disabled ◉ Enabled	
SNMP Enabled Traps	☑ Cold Start	
	☑ PTP Link Status Change	
	☑ DFS Channel Change	
	☑ DFS Impulse Interference	
	☐ Enabled Diagnostic Alarms	
SNMP Trap Version	○ SNMP version 1 ◉ SNMP version 2c	
SNMP Trap IP Address	10 . 145 . 9 . 52	
SNMP Trap Port Number	162	
SNMP Community String	its-snmp	
SNMP Port Number	161	

Simple Mail Transfer Protocol (SMTP)

SMTP Email Alert	◉ Disabled ○ Enabled	
SMTP Enabled Messages	☑ PTP Link Status Change	
	☑ DFS Channel Change	
	☑ DFS Impulse Interference	
	☐ Enabled Diagnostic Alarms	
SMTP Server IP Address	0 . 0 . 0 . 0	
SMTP Server Port Number	25	
SMTP Source Email Address		
SMTP Destination Email Address		
Send SMTP Test Email	☐ Yes	

Clock

SNTP State	○ Disabled ◉ Enabled	
SNTP Server IP Address	10 . 45 . 17 . 10	
SNTP Server Port Number	123	
SNTP Poll Interval	3600	Seconds
SNTP Sync	In Sync	
SNTP Last Sync	28-May-2009 10:08:03	
System Clock	28-May-2009 10:23:51	
Time Zone	GMT -07.00	
Daylight Saving	○ Disabled ◉ Enabled	

Submit Updated Configuration | Reset Form

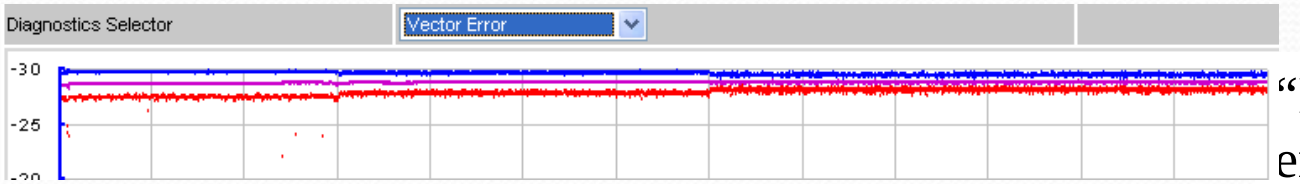
Radio Feature Highlights

(Diagnostic Plotter #1)

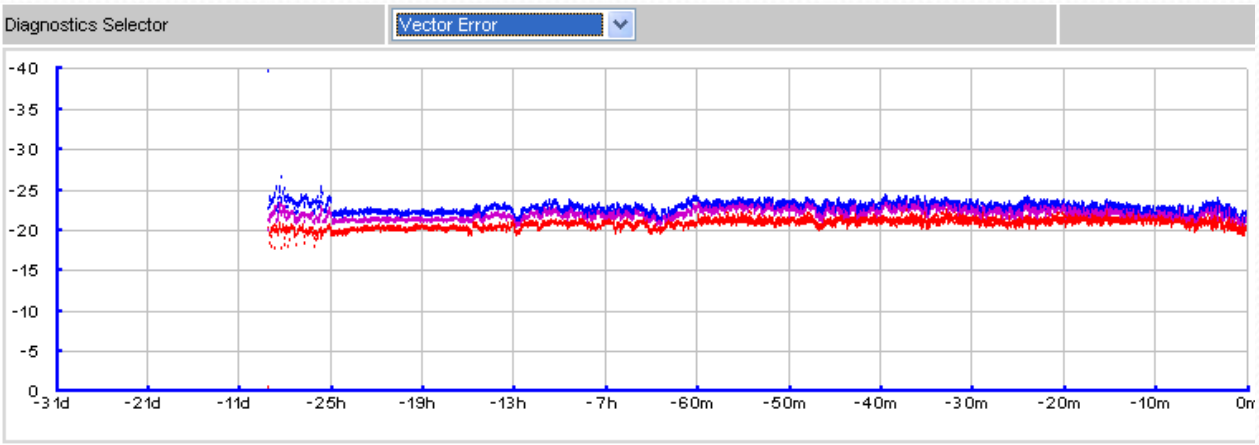
- Requires knowledge of path environment and link configuration
- Plot displays three traces
  - Maximum values are red, mean values are purple and minimum values blue
  - Ideal trace is straight red line
- Horizontal axis spans time: 60 minutes, 24 hours, 30 days
- Vertical axis spans signal level
- Correct interpretation: high numbers can be good or can be bad

Radio Feature Highlights

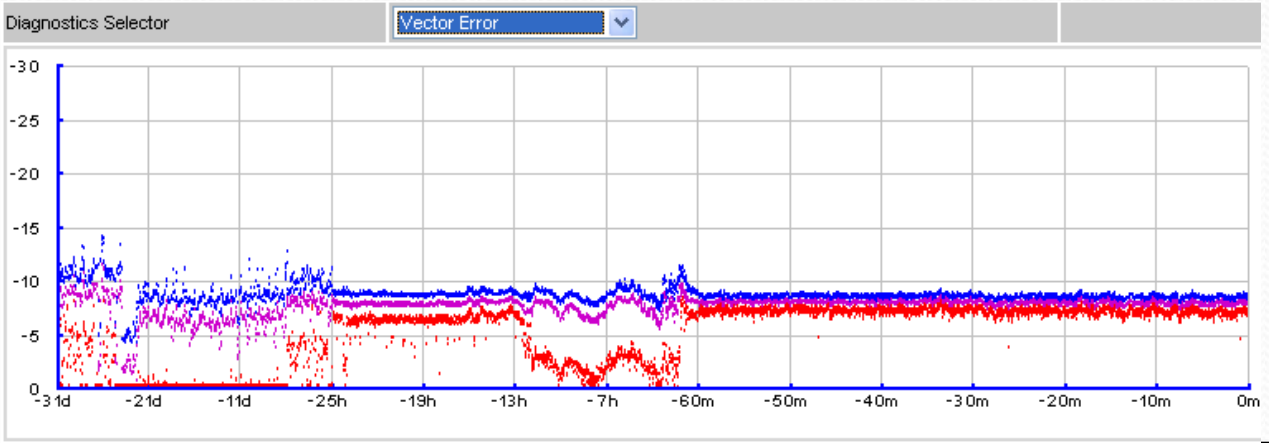
(Vector Error #1)



"Normal" plot with little error and minimal variation



Plot with of two dish configuration needing alignment



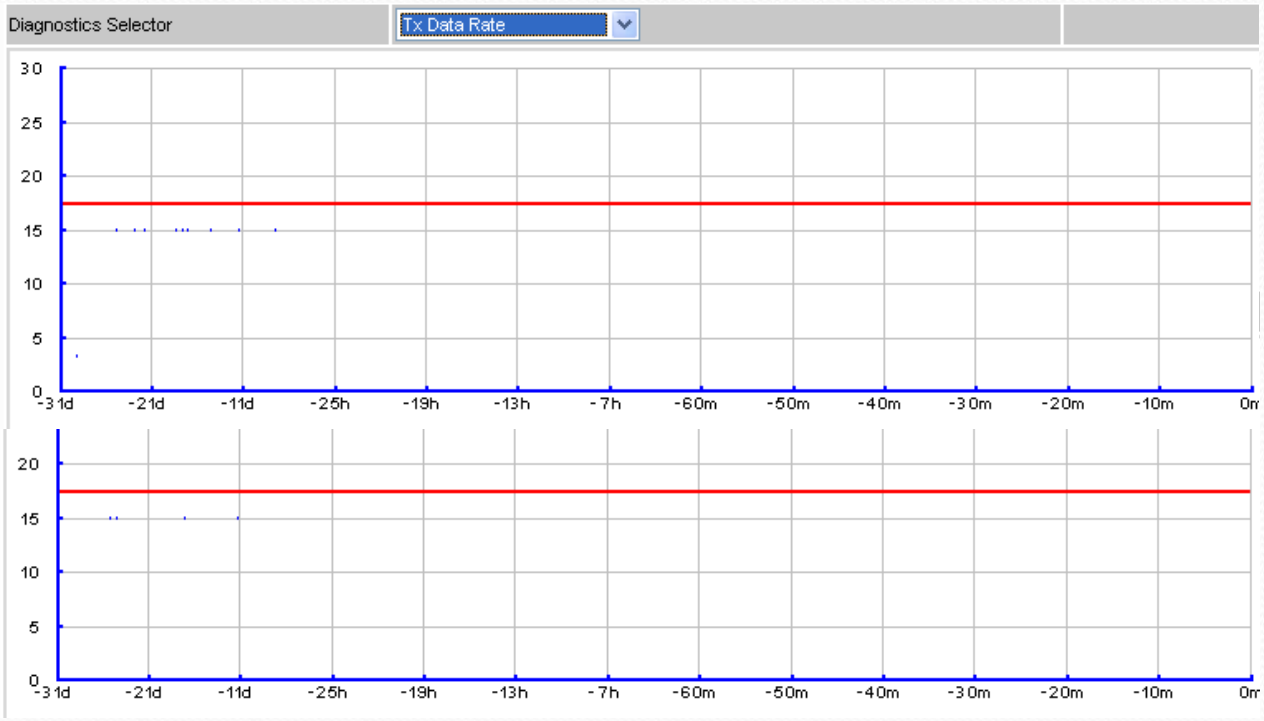
Plot with Fresnel incursion

Path is near line-of-sight with very high error

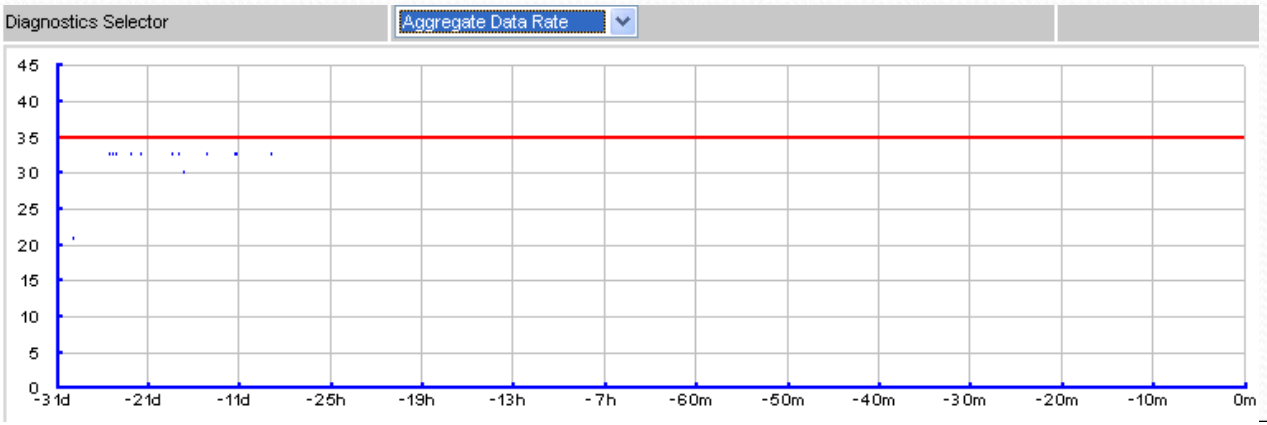
Variation in the hourly plots possibly linked to time of day and thermals or weather event

Radio Feature Highlights

(Data Rate #1)



Transmit and Receive rates very stable and solid (straight red line)

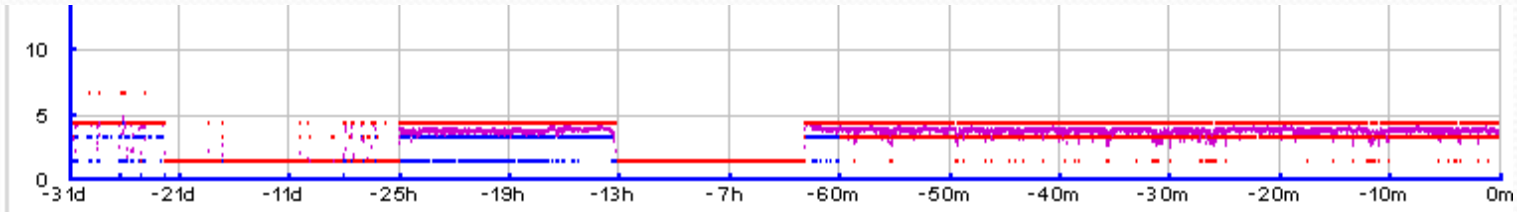


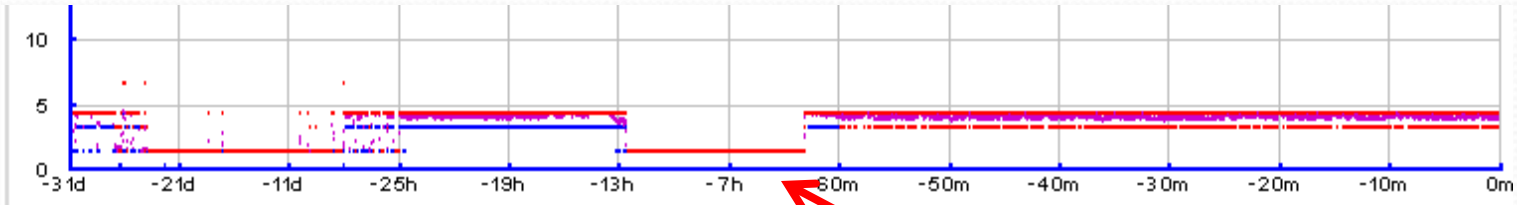
Aggregate rate is adding of both rates and again is very stable

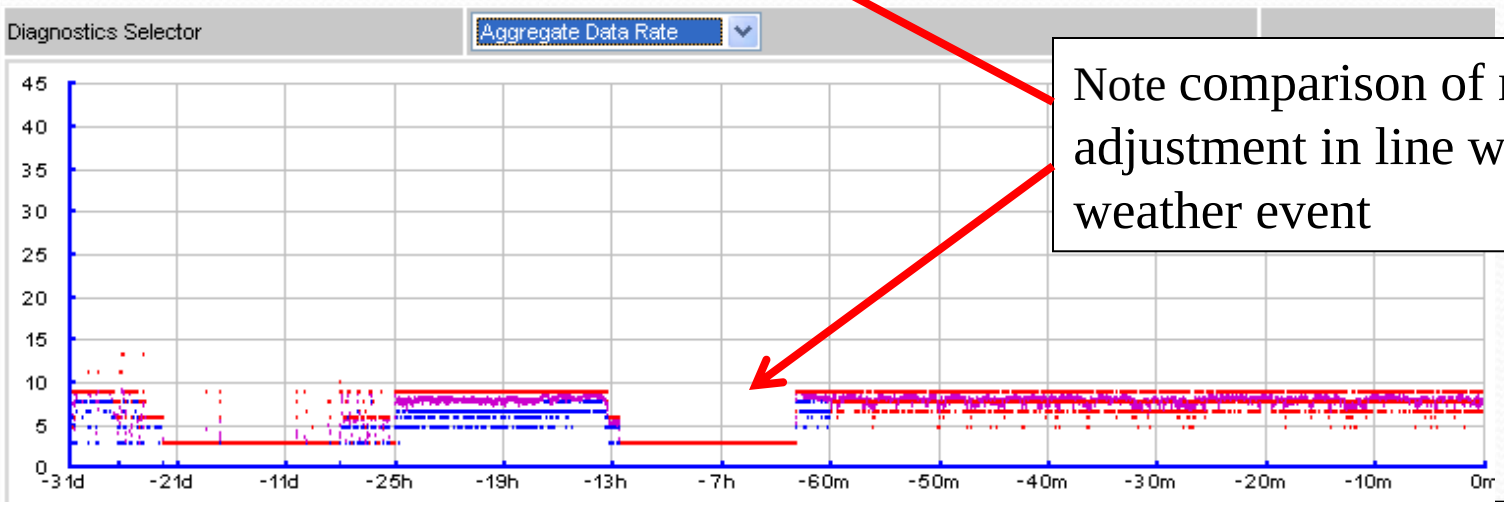
Radio Feature Highlights

(Data Rate #2)

Plots are from radio with Fresnel incursion mentioned above. Data rate plots vary in sync where modulation has “adapted” to more robust scheme .



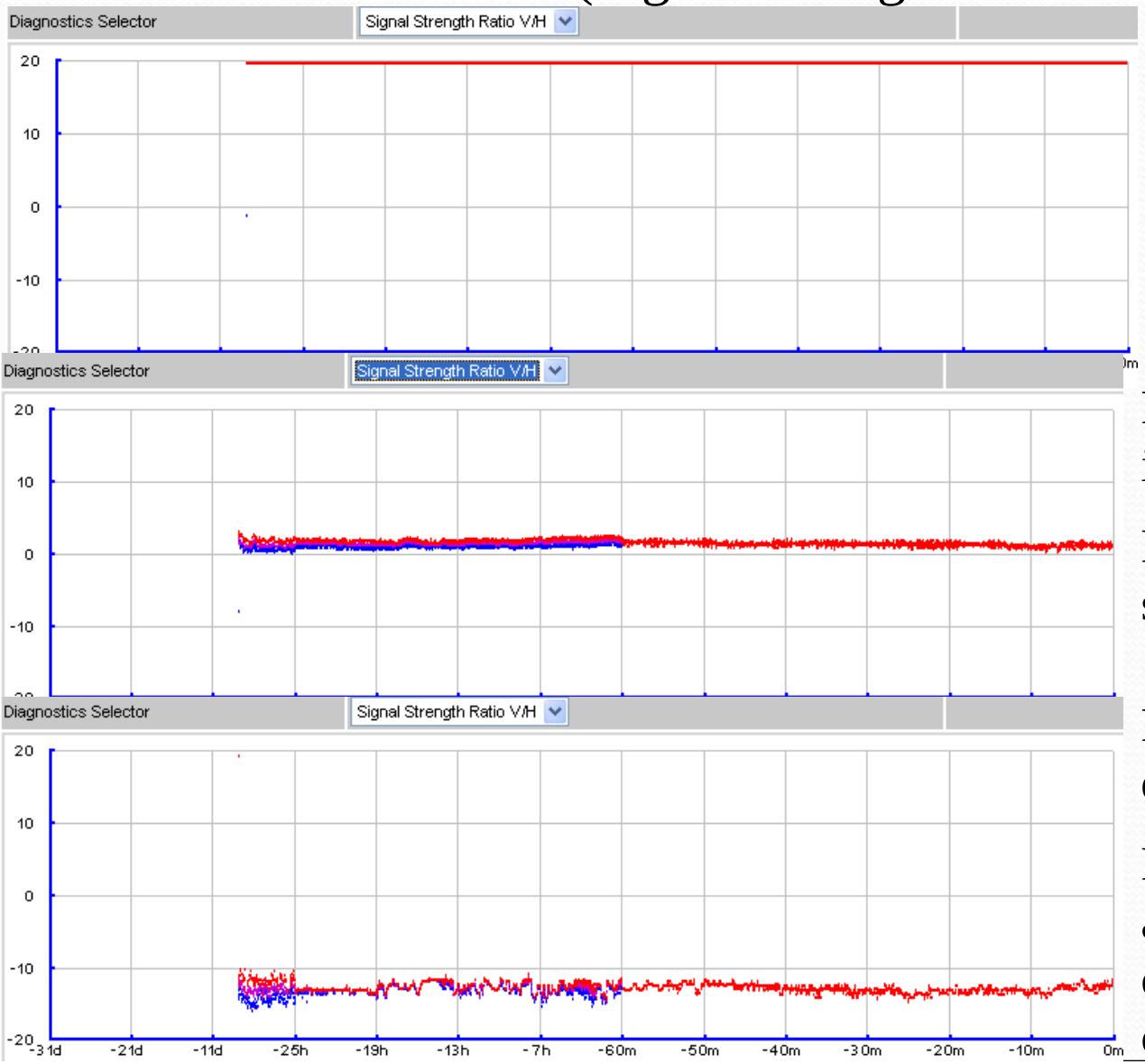




Note comparison of modulation adjustment in line with thermal or weather event

Radio Feature Highlights

(Signal Strength Ratio #1)



Radio using only vertical pole and antenna

Radio using both poles and identical antennas

Plot should be near zero and solid red line

Radio using both poles but different sized antennas

Plot should reflect gain advantage of one antenna over the other (12 db in this case)

Second Phase of Backbone Installation

- Existing branch covering Interstate 80
  - Implemented AES encryption on radio links
  - Upgraded capacity of radio links doubling throughput
  - Both efforts done via software from desktop
  - Spares inventory established, operations & maintenance training continuing
- Branch Expansions (as seen on CY2009 Backhaul Expansion slide)
  - Branches covering I25 and I90
  - Alternate routes using 4.9 GHz radios
  - Two branches to cover remote maintenance shops and non-interstate routes where significant roadside devices are deployed
  - Motorola’s newest radios being used; the PTP500 version

Second Phase of Backbone Installation

(continuation)

- Staying ahead of the rapid deployment of roadside devices
  - FY09 Construction: 14 DMS signs, 29 RWIS stations, 28 Webcams, 21 Speed Sensors
  - FY10: Four new Variable Speed Limit zones with numbers of devices TBD
- Numerous requests received to upgrade comms on existing roadside devices and for connectivity into the Backbone
  - Accomplished on a time and funds available basis
  - Uncounted number of devices
- Keeping an eye on the future
  - Additional stakeholders
  - Mobile broadband

Questions ?